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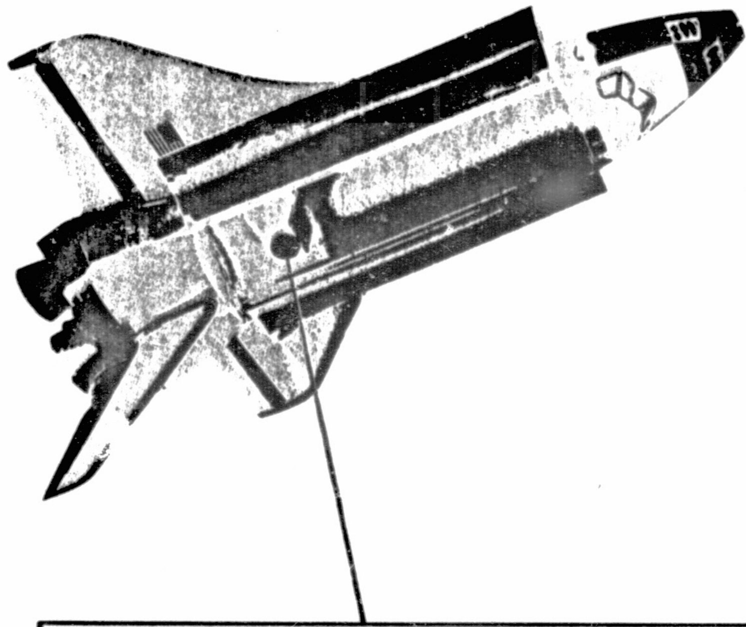

SHUTTLE/TETHERED SATELLITE
SYSTEM DEFINITION STUDY EXTENSION

FINAL REPORT (F80-10)
JUNE 30, 1980

(NASA-CR-171473) SHUTTLE-TETHERED SATELLITE SYSTEM DEFINITION STUDY EXTENSION Final Report (Ball Aerospace Systems Div., Boulder) 295 p HC A13/MF A01 CSCL 22A

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SHUTTLE/TETHERED SATELLITE
SYSTEM DEFINITION STUDY EXTENSION

FINAL REPORT

F80-10

JUNE 30, 1980

PREPARED FOR:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
MARSHALL SPACE FLIGHT CENTER

CONTRACT NAS8-32853

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DIRECTOR OF PROGRAM DEVELOPMENT

INTRODUCTION

A system requirements definition and configuration study (Phase B) of the Tethered Satellite System (TSS) was conducted by Ball Aerospace Division of the Ball Corporation under contract NAS8-32853 with the NASA Marshall Space Flight Center during the period 14 November 1977 to 27 February 1979. Subsequently a study extension was conducted during the period 13 June 1979 to 30 June 1980, for the purposes of refining the requirements identified during the main phase of the study, and studying in some detail the implications of accommodating various types of scientific experiments on the initial verification flight mission.

The following pages contain an executive overview of the Tethered Satellite System definition developed during the study and report the results of specific study tasks undertaken in the extension phase of the study.

Feasibility of the Tethered Satellite System has been established with reasonable confidence and the groundwork laid for proceeding with hardware design for the verification mission.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

TSS MISSION

TETHERED SATELLITE SYSTEM

MISSION

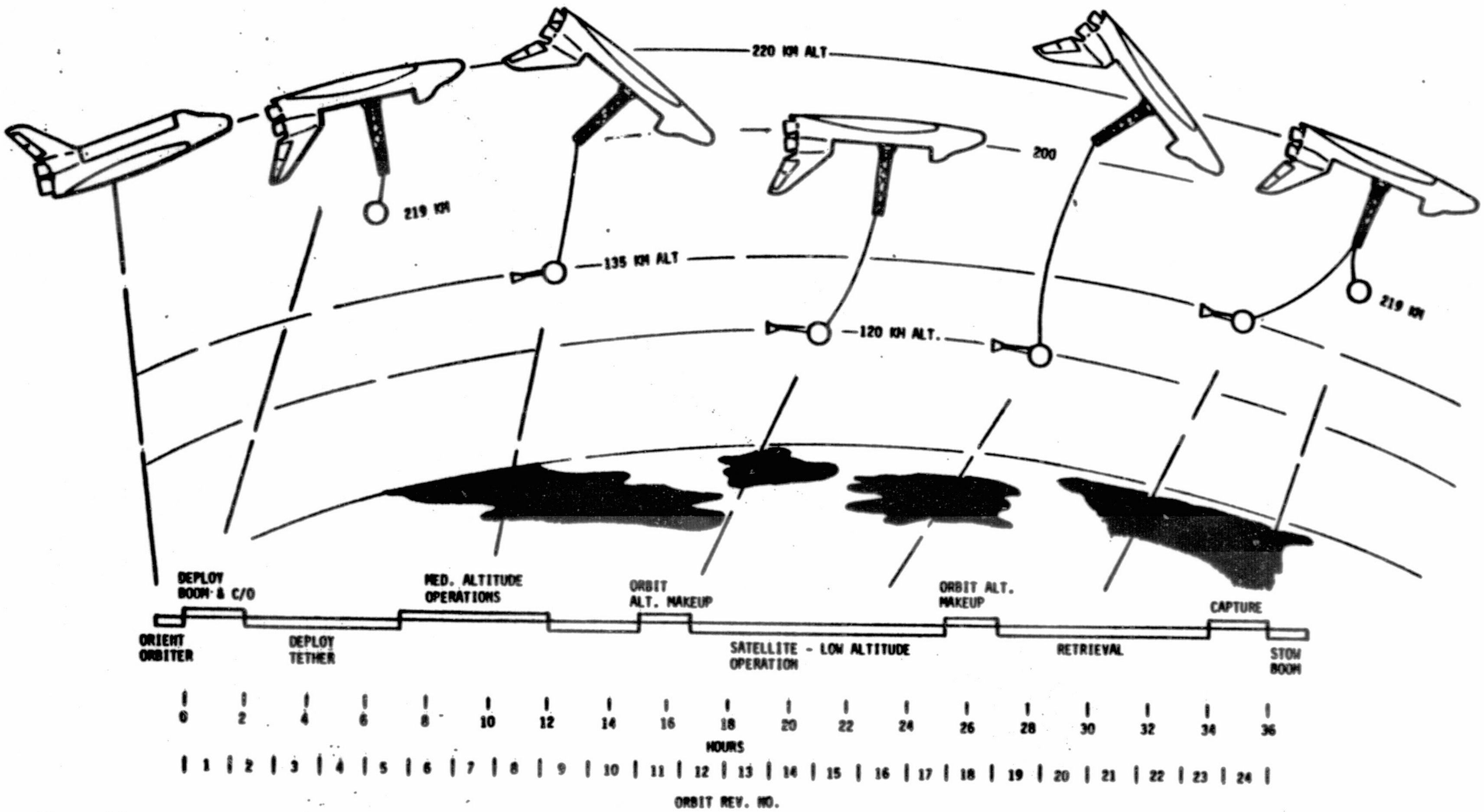
VERIFICATION FLIGHT

TO VERIFY THE SOUNDNESS OF THE T-SAT CONCEPT BY PERFORMING A DEPLOYMENT/RETRIEVAL

FOLLOW-ON FLIGHTS

TO PROVIDE A REUSABLE SHUTTLE FACILITY TO SUPPORT A WIDE VARIETY OF SCIENTIFIC PAYLOADS

TSS VERIFICATION MISSION—FLIGHT PROFILE



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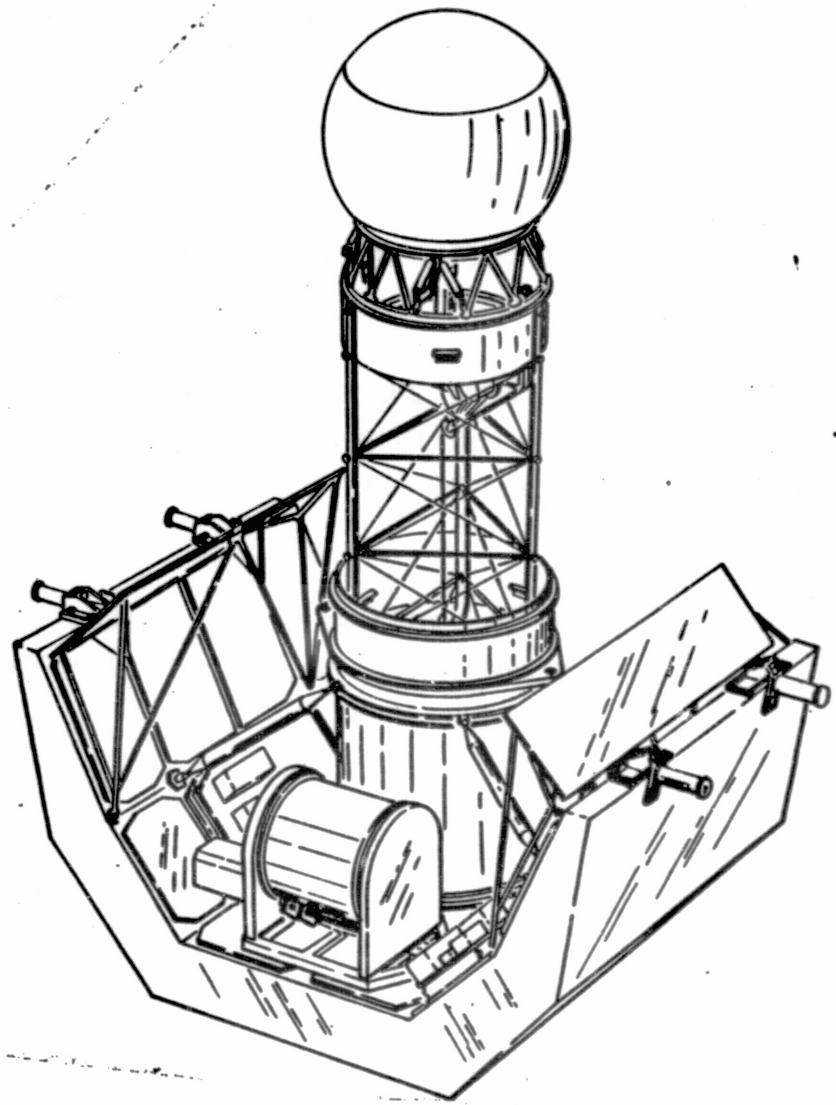
BASELINE CONFIGURATION

THE BASELINE CONFIGURATION OF THE TSS DEPLOYER USES THE SPACELAB PALLET AS AN INTERFACE STRUCTURE. THE PALLET CAN BE MOUNTED IN ANY OF THE AVAILABLE POSITIONS IN THE ORBITER PAYLOAD BAY.

THE SATELLITE IS RESTRAINED AT THE OUTER END OF A COILABLE LATTICE BOOM 1.2 METERS IN DIAMETER AND 10 METERS IN LENGTH WHEN FULLY EXTENDED. THE TSS DEPLOYER COMPONENTS ARE MOUNTED ON THE SPACELAB COLD PLATES AND THE DEPLOYER STRUCTURE INTERFACES WITH STANDARD SPACELAB PALLET MECHANICAL ATTACH POINTS.

BASELINE CONFIGURATION – BOOM PARTIALLY EXTENDED

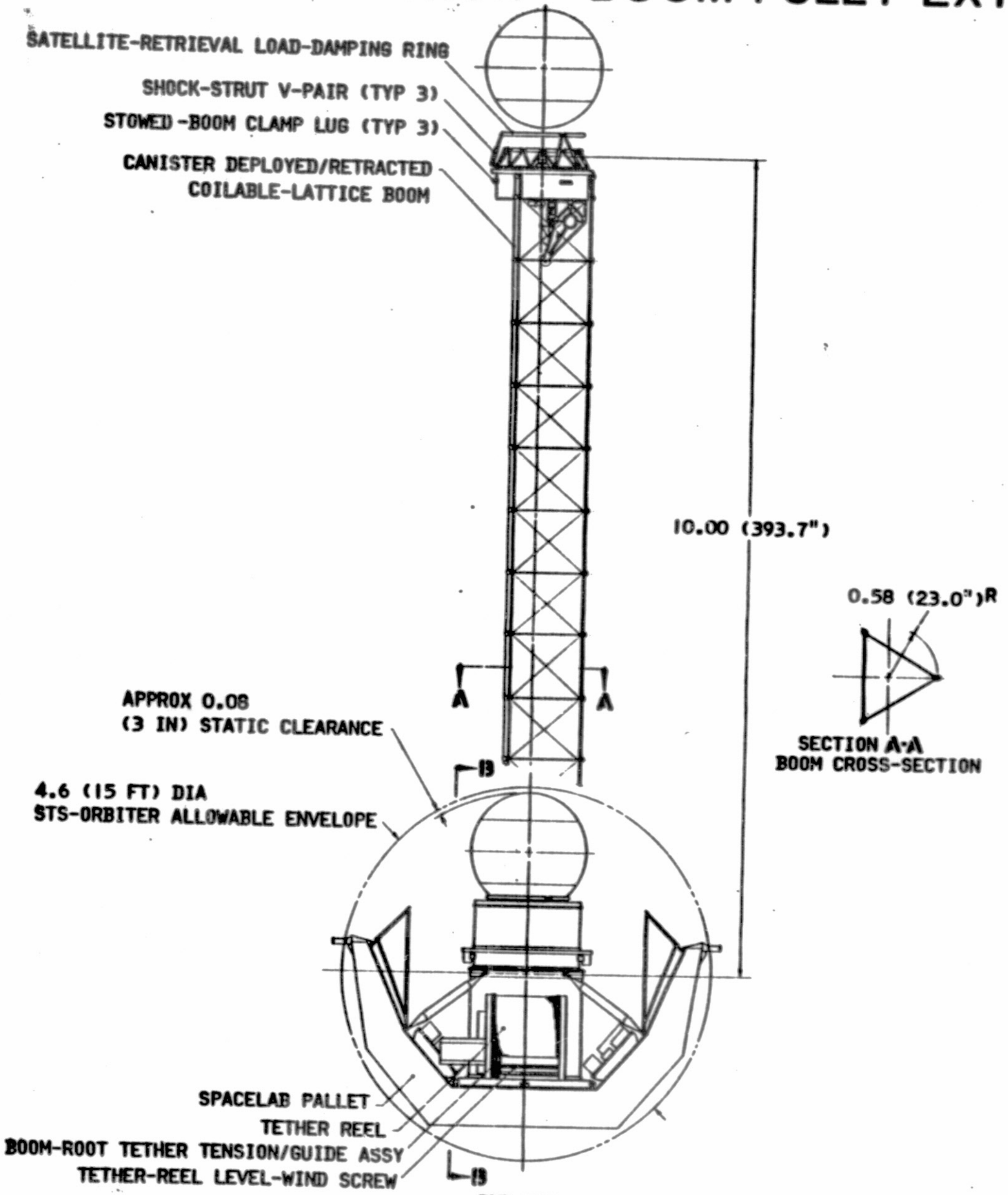


SATELLITE IS RELEASED AFTER THE EXTENSION OF THE BOOM AND THE BOOM REMAINS EXTENDED DURING THE FLIGHT OF THE SATELLITE AND IS RETRACTED AFTER RECAPTURE.

THE TETHER PASSES FROM THE REEL AT THE BASE OF THE BOOM THROUGH THE CENTER OF THE TRIANGULAR CROSS-SECTION BOOM TO THE TETHER TENSION CONTROLLERS LOCATED AT THE TIP OF THE BOOM.

THE TIP OF THE BOOM IS EQUIPPED WITH A SPRING-LOADED DOCKING RING AND DROGUE FITTING FOR RELEASING AND RESTOWING THE SATELLITE.

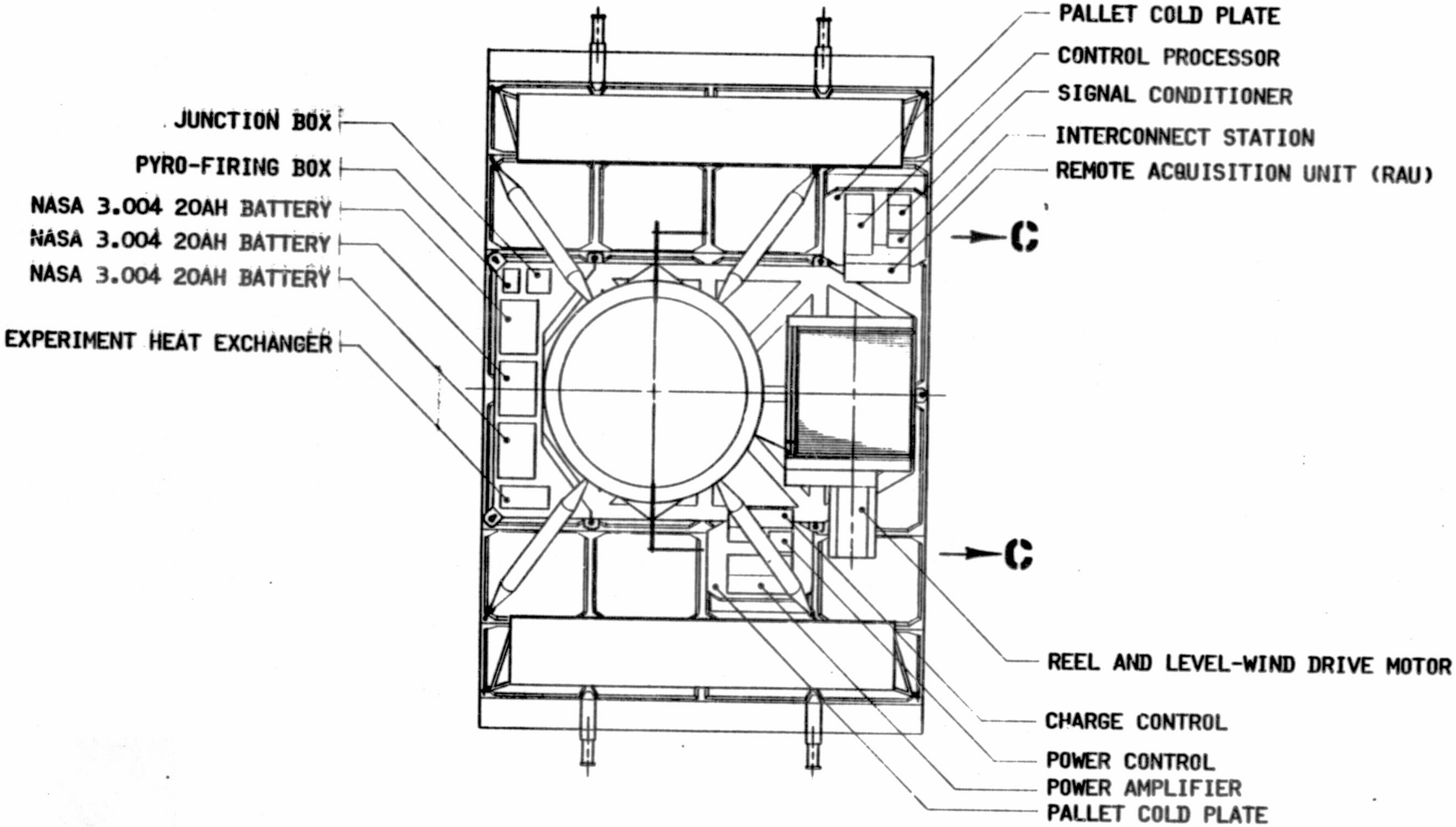
BASELINE CONFIGURATION - BOOM FULLY EXTENDED



END VIEW
LOOKING PARALLEL TO ORBITER X_0 AXIS

RADIATIVE PANELS LOCATED ALONG THE RAILS OF THE PALLET STRUCTURE DISSIPATE EXCESS ELECTRICAL ENERGY GENERATED DURING DEPLOYMENT OF THE SATELLITE, DECREASING THE THERMAL LOAD WHICH WOULD BE OTHERWISE IMPOSED ON THE SPACELAB OR ORBITER COOLING SYSTEM.

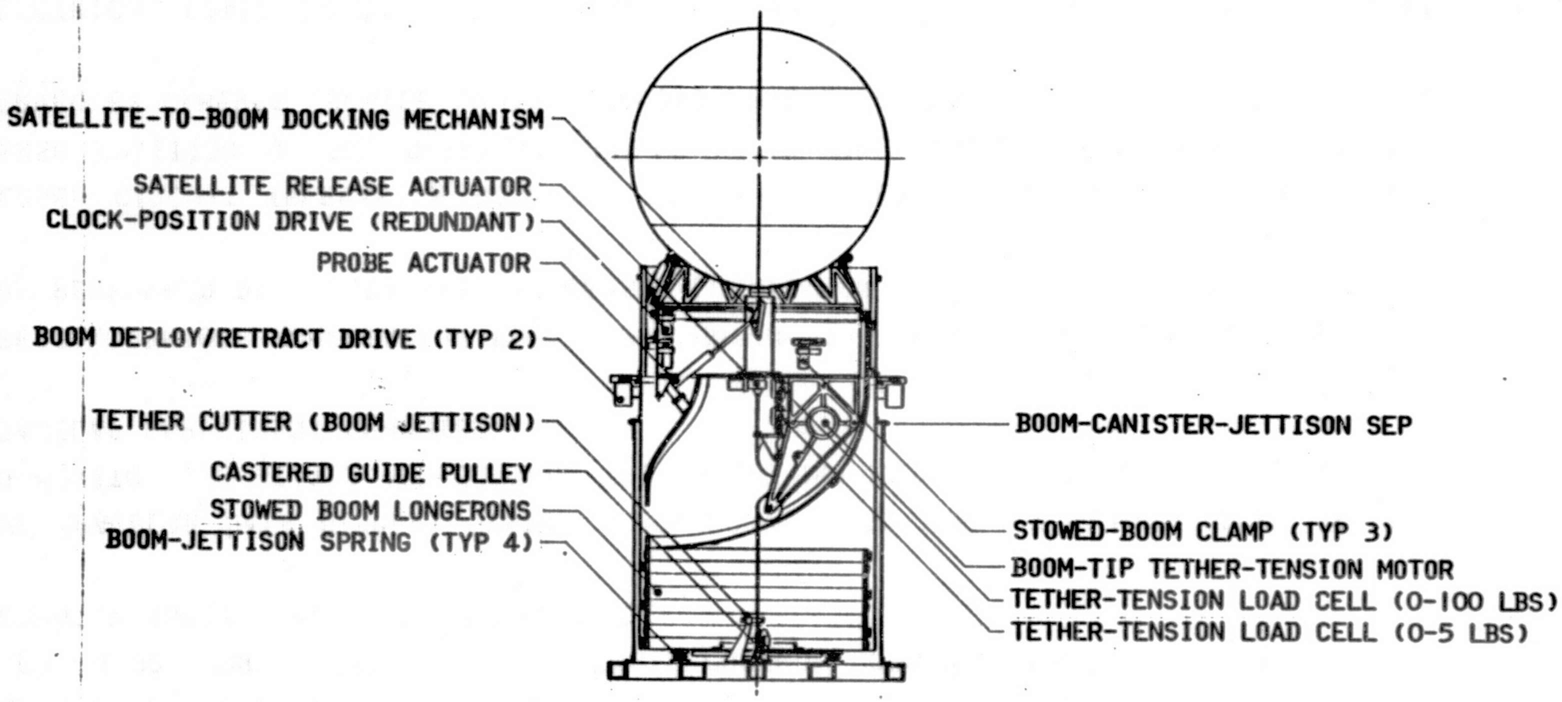
DEPLOYER - PLAN VIEW
(LOOKING PARALLEL TO ORBITER Zo AXIS)



IN THE STOWED POSITION THE BOOM IS CONTAINED IN A CANISTER. IF FOR SOME REASON, IT SHOULD BE IMPOSSIBLE TO RESTOW THE BOOM, THE BOOM CAN BE JETTISONED AND THE TETHER LINE SEVERED TO ENABLE RECLOSING OF THE ORBITER PAYLOAD BAY DOORS.

A CLOCKING DRIVE MECHANISM LOCATED AT THE OUTER END OF THE BOOM ALLOWS ROTATION OF THE SATELLITE ABOUT THE BOOM LONGITUDINAL AXIS TO ENABLE STORING THE SATELLITE IN A PREFERRED POSITION ON THE BOOM TIP.

DEPLOYER-BOOM-INTERNAL ARRANGEMENT



SECTION C-C
ROTATED 90° CCW

THE ORBITER DATA DISPLAY AND KEYBOARD UNIT, LOCATED ON THE AFT FLIGHT DECK, IS USED TO MONITOR THE STATUS AND EXECUTE CONTROL COMMANDS VIA THE GENERAL PURPOSE COMPUTER AND THE PAYLOAD INTERROGATOR.

THE SPACELAB DATA DISPLAY SYSTEM, LOCATED ALSO ON THE AFT FLIGHT DECK, IS USED TO MONITOR THE STATUS AND CONTROL THE PALLET-MOUNTED DEPLOYER SUBSYSTEMS VIA THE SPACELAB EXPERIMENT COMPUTER.

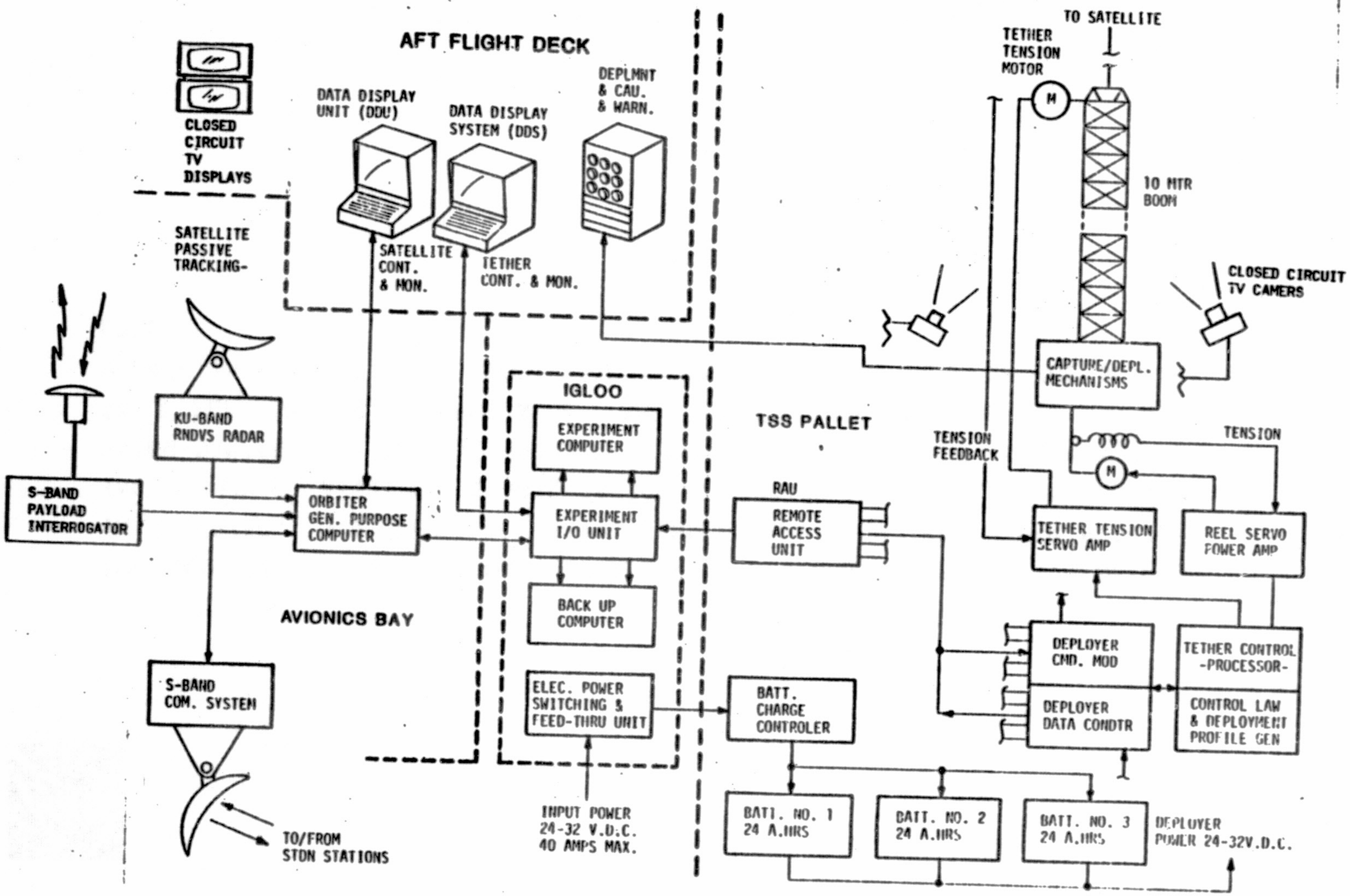
SPECIAL PURPOSE COMPUTATION FUNCTIONS, UNIQUE TO THE TETHERED SATELLITE DEPLOYER ARE PERFORMED BY A DEDICATED PROCESSOR LOCATED ON THE DEPLOYER PALLET.

CLOSED CIRCUIT TELEVISION DISPLAYS ON THE AFT FLIGHT DECK INDICATE THE TRANSVERSE POSITION OF THE SATELLITE RELATIVE TO THE BOOM AT SHORT RANGES, AS OBSERVED BY CAMERAS LOCATED ON THE DEPLOYER PALLET RAILS.

ELECTRICAL POWER IS SUPPLIED TO THE DEPLOYER BY THE ORBITER OR SPACELAB POWER BUS VIA THE BATTERY CHARGE CONTROLLER LOCATED ON THE PALLET.

THREE OR FOUR NICKEL CADMIUM STORAGE BATTERIES, LOCATED ON THE PALLET, STORE EXCESS ELECTRICAL ENERGY DURING PAYOUT OF THE TETHER AND DELIVER CURRENT TO THE REELING MECHANISM DURING PEAK LOAD PERIODS, SUCH AS THOSE INCURRED DURING RETRIEVAL.

ORBITER-MOUNTED SUPPORT EQUIPMENT



THE MAIN SATELLITE STRUCTURE CONSISTS OF A SPHERICAL SHELL 1.4 METERS IN DIAMETER. THE SATELLITE HANGS PENDULOUSLY FROM THE TETHER PROVIDING INHERENT ATTITUDE STABILIZATION IN PITCH AND ROLL, THE MOTION BEING DAMPED BY A PASSIVE INTERNAL DAMPER. YAW ATTITUDE IS STABILIZED BY A FLAT VERTICAL UNFURLABLE AERODYNAMIC VANE AT THE END OF THE RETRACTABLE THREE METER STEM BOOM EXTENDING TO THE REAR OF THE SATELLITE.

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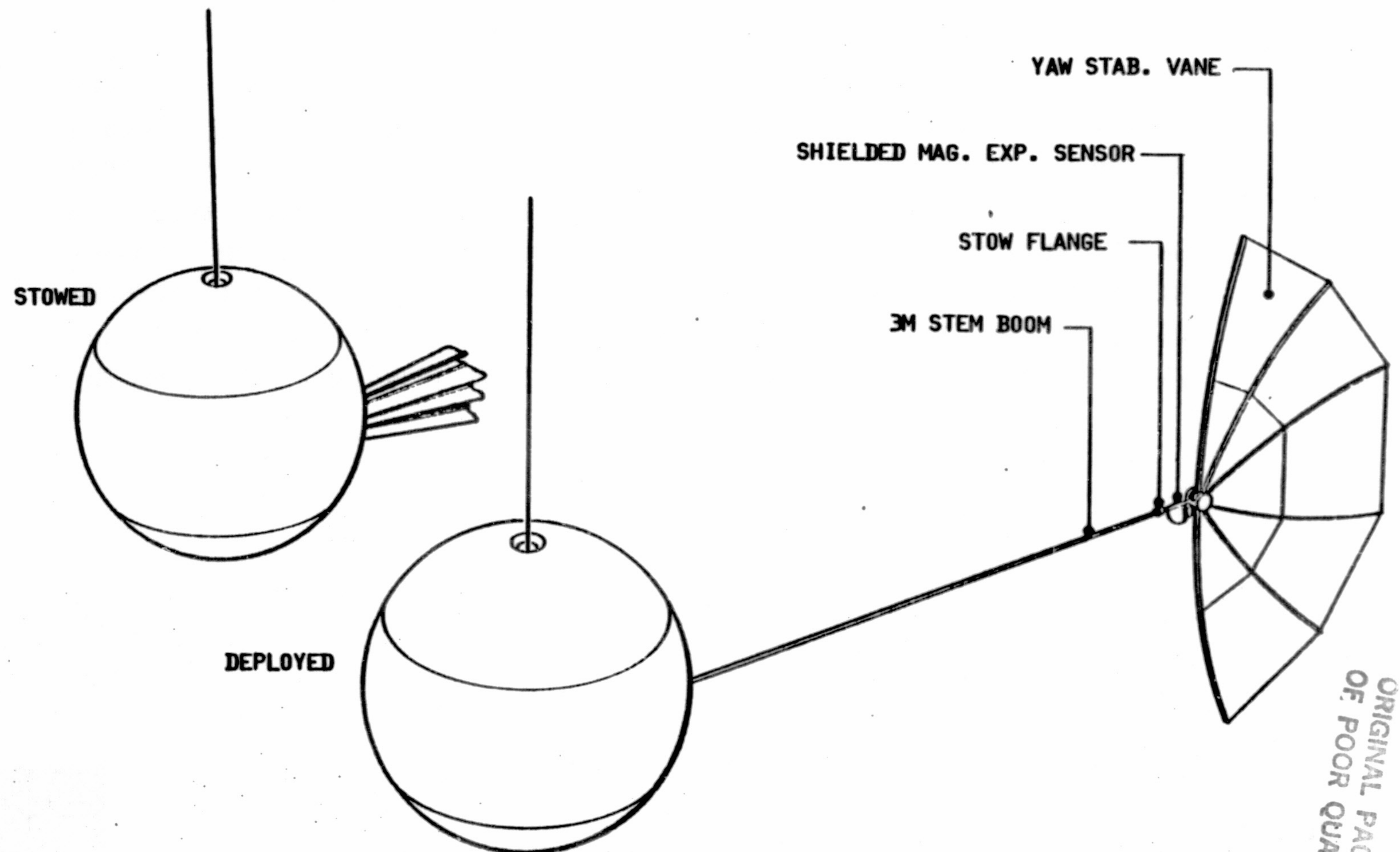
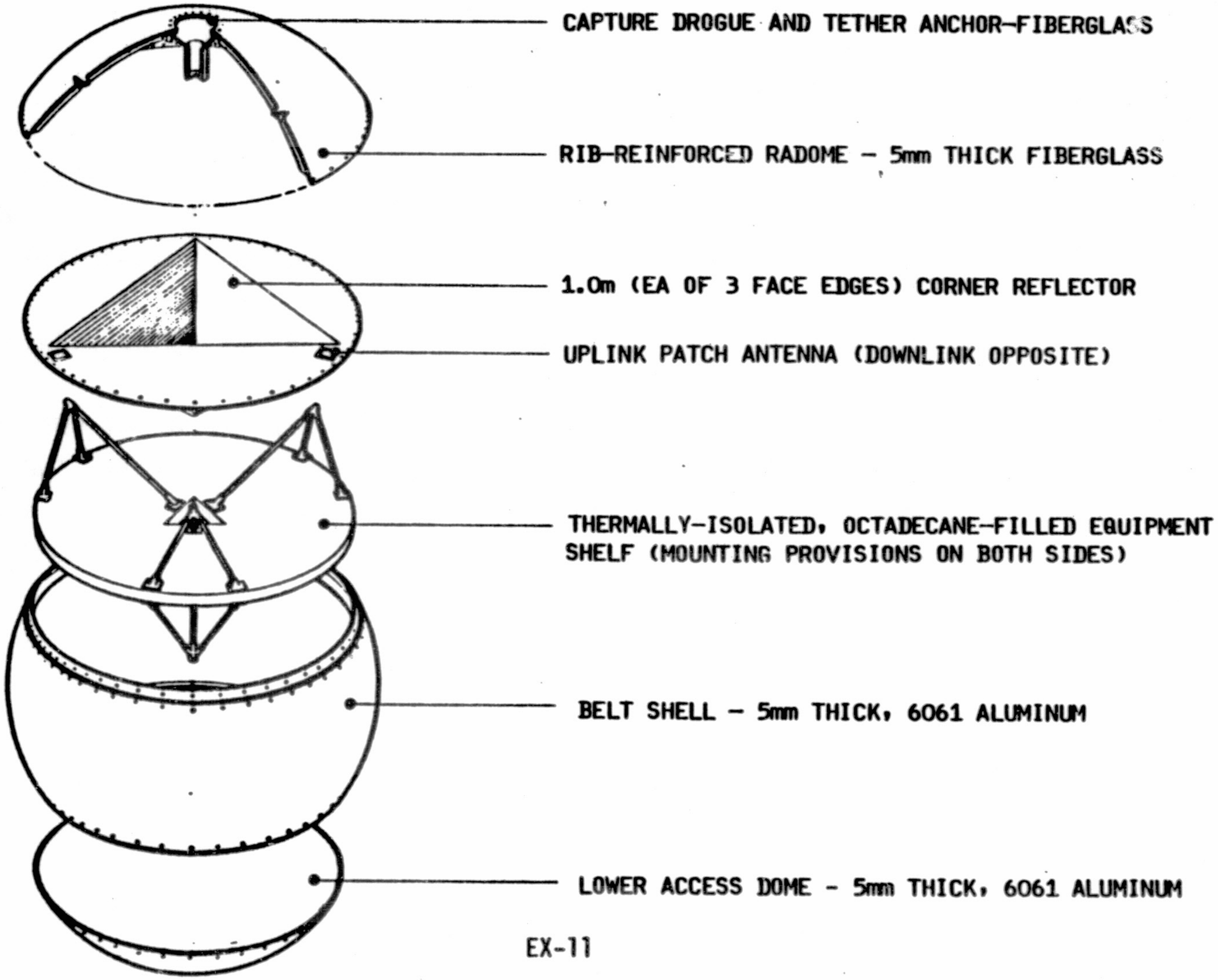
TSS SPACECRAFT CONCEPTUAL DESIGN ADAPTED FOR "COMBINATION" MISSION EXPERIMENT COMPLEMENT



THE SATELLITE EQUIPMENT SHELF IS ISOLATED THERMALLY FROM THE EXTERNAL SHELL STRUCTURE. THE SHELF IS FILLED WITH OCTADECANE MATERIAL WHICH ABSORBS HEAT ON MELTING, HELPING TO STABILIZE THE TEMPERATURE OF THE SHELF. THE UPPER PORTION OF THE SPACECRAFT CONTAINS A RADAR CORNER REFLECTOR ENABLING DETERMINATION OF THE SATELLITE POSITION UP TO RANGES OF GREATER THAN 100 KILOMETERS USING THE ORBITER RENDEVOUS RADAR. THE UPPER SHELL CAP OF THE STRUCTURE IS A RADAR TRANSPARENT RADOME WHICH COVERS THE RETRODIRECTIVE CORNER REFLECTOR.

TETHERED SATELLITE EQUIPPED WITH CORNER REFLECTOR TO ENHANCE RADAR CROSSECTION



THE SATELLITE ELECTRICAL SUBSYSTEMS ARE POWERED FROM INTERNAL HIGH ENERGY DENSITY BATTERIES WHICH PROVIDE SUFFICIENT ENERGY FOR A 35-HOUR MISSION, INCLUDING 23 HOURS OF ON-STATION OPERATION OF AN EXPERIMENT CONSUMING UP TO 17 WATTS OF AVERAGE POWER.

EXPERIMENT POWER MAY BE INCREASED BY ADDING ADDITIONAL BATTERIES.

THE ENGINEERING INSTRUMENTATION COMPLEMENT ENABLES MONITORING AND DIAGNOSIS OF THE THERMAL AND DYNAMIC BEHAVIOR OF THE SATELLITE DURING THE MISSION.

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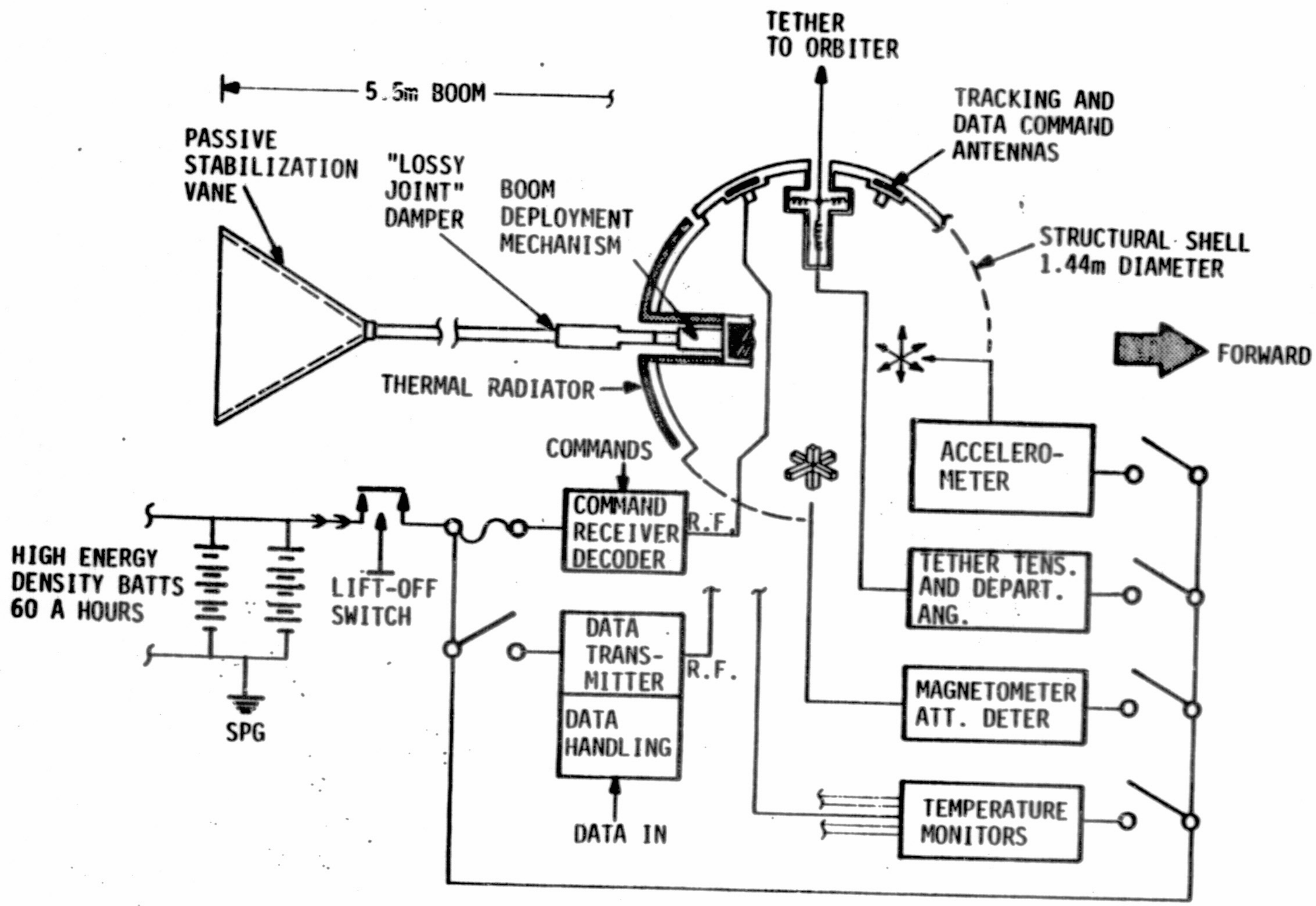
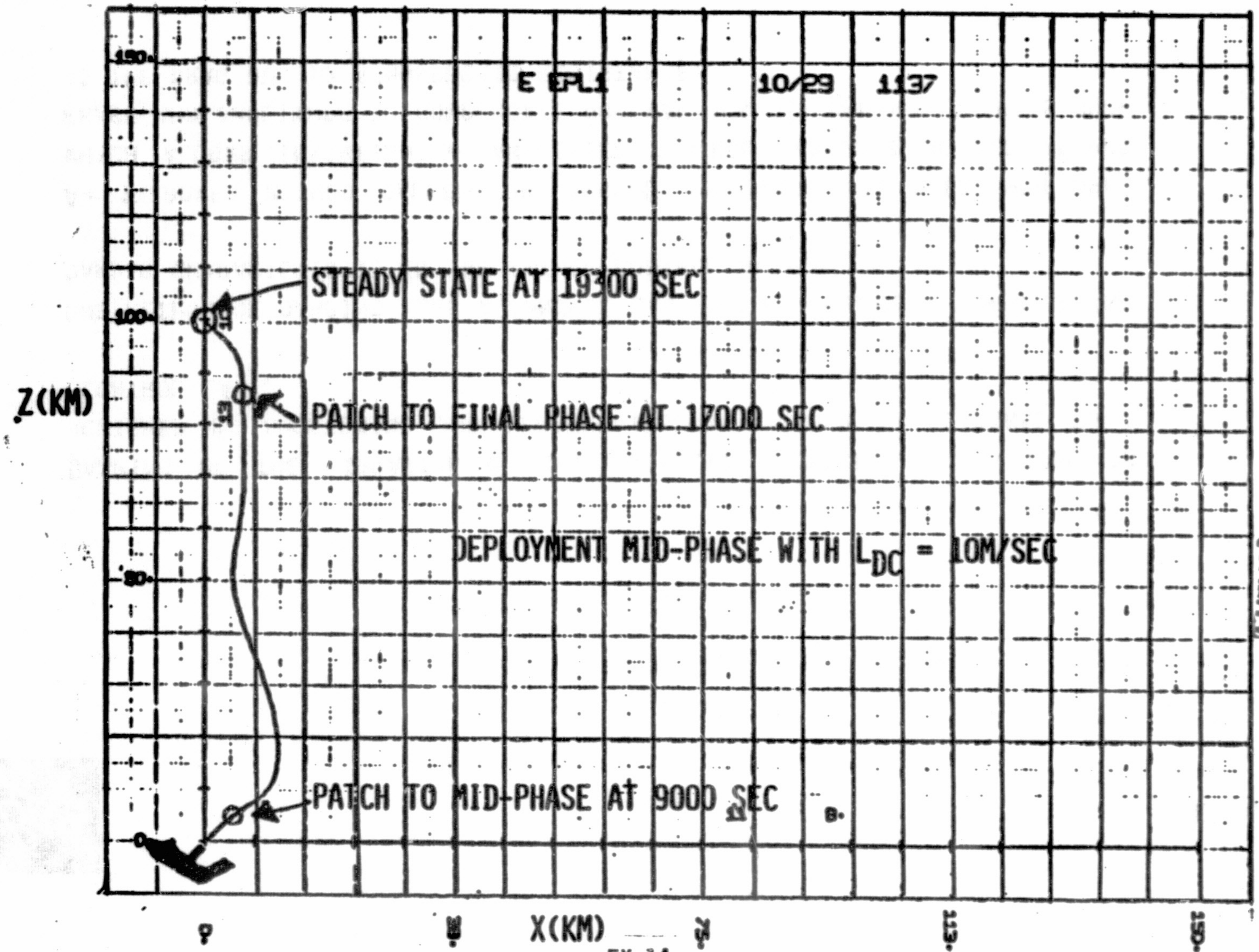
TETHERED SATELLITE FUNCTIONS – BASELINE CONFIGURATION



DEPLOYMENT/RETRIEVAL DYNAMICS

TYPICAL DEPLOYMENT OF THE SATELLITE INVOLVES SEPARATION OF THE SATELLITE FROM THE BOOM TIP WITH A SMALL INITIAL VELOCITY, FOLLOWED BY AN INITIAL DEPLOYMENT RATE WHICH IS INCREASED IN PROPORTION TO THE LENGTH OF TETHER PAID OUT (EXPONENTIAL RATE), THEN A TRANSITION TO A CONSTANT RATE OF ABOUT TEN METERS PER SECOND. THE TERMINAL PHASE OF DEPLOYMENT INVOLVES A SECOND PHASE OF EXPONENTIALLY INCREASING VELOCITY TO THE FINAL POSITION, THE TOTAL DEPLOYMENT MANEUVER CONSUMING ABOUT FIVE HOURS. THE TOTAL DEPLOYMENT TIME CAN BE SHORTENED SOMEWHAT BY THE SELECTION OF APPROPRIATE ORBITER ATTITUDES DURING THE INITIAL DEPLOYMENT PHASE.

TYPICAL DEPLOYMENT CONTROL



DAMPING OF THE LIBRATION OF THE SATELLITE BENEATH THE ORBITER IS ACHIEVED BY SHORTENING AND LENGTHENING THE TETHER IN RESPONSE TO A "CONTROL LAW".

ONE METHOD OF DAMPING USES A CONTROL LAW WHICH EMULATES A TUNED-SPRING DAMPER CHARACTERISTIC IN THE TETHER CONTROL SYSTEM.

AN IMPROVED METHOD CALLED THE "MODEL FOLLOWER" HAS BEEN DEVELOPED WHICH ALLOWS INSERTION OF AMPLIFIED CONTROL TENSIONS OF THE PROPER PHASE AND AMPLITUDE TO COMPENSATE FOR VARIOUS DISTURBANCE EFFECTS SUCH AS THE DRAG DUE TO ATMOSPHERIC RESISTANCE.

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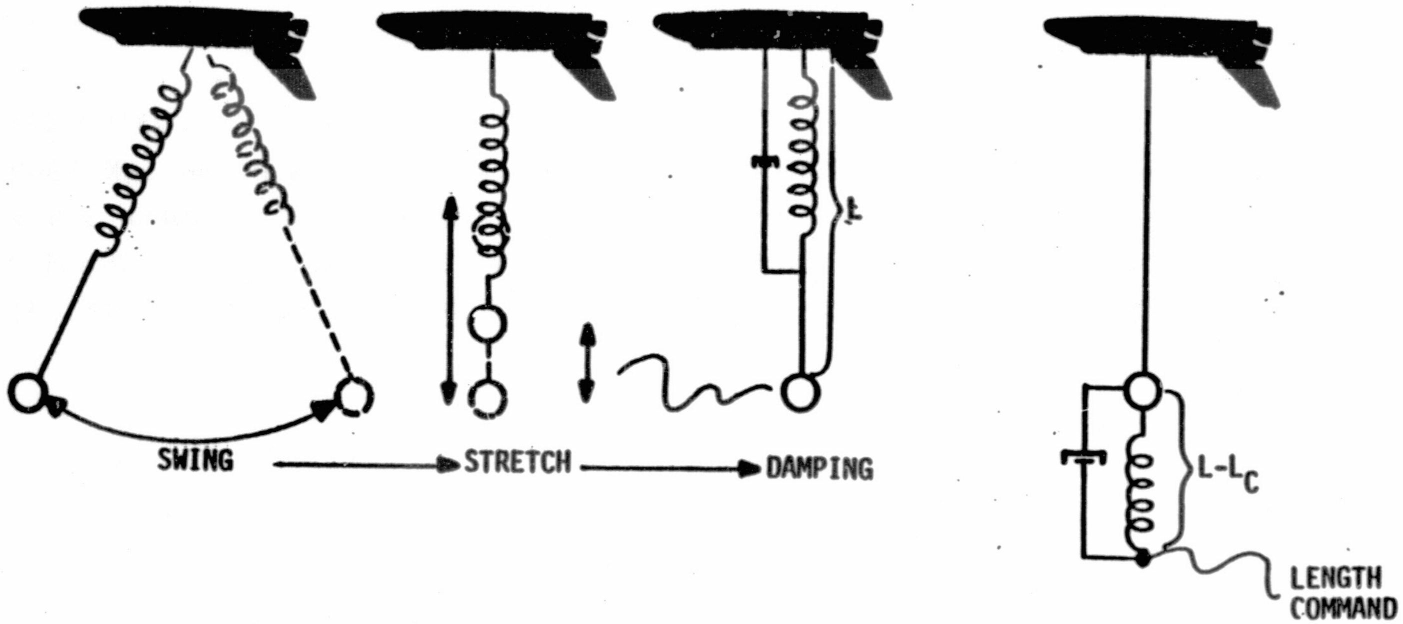
STEADY STATE CONTROL CONCEPTS



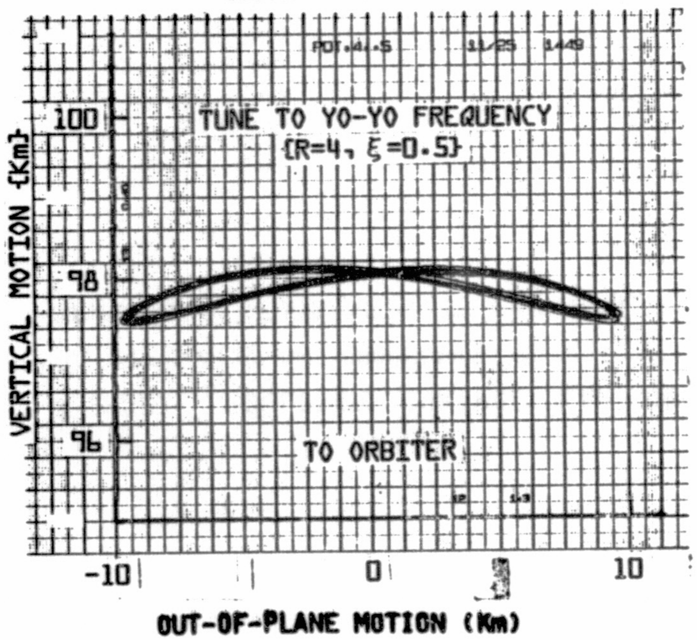
TUNED SWING-STRETCH COUPLER

MODEL FOLLOWER

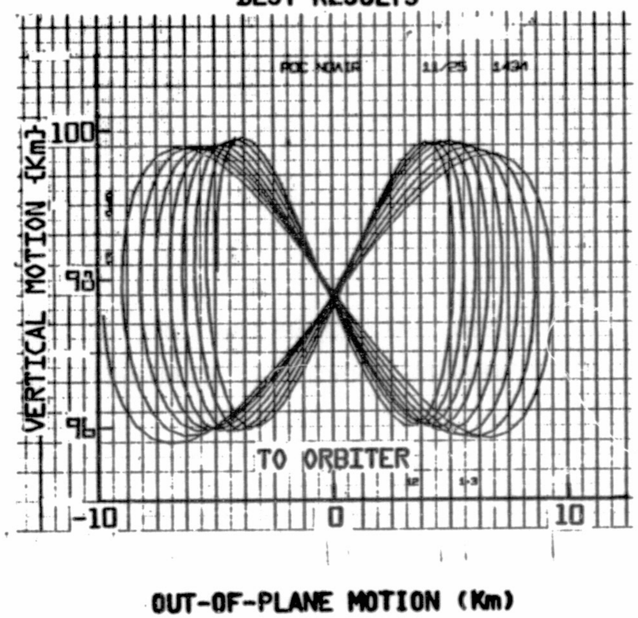
THE MODEL FOLLOWER CONTROL LAW RESULTS IN SUBSTANTIAL DAMPING AT THE EXPENSE OF SOME INCREASE IN VERTICAL MOTION OF THE SATELLITE. STEADY STATE DAMPING PERFORMANCE WITH THE SWING STRETCH COUPLER, HOWEVER, DOES NOT PRODUCE SUFFICIENT DAMPING FOR MISSIONS OF THE DURATION CONTEMPLATED.

IMPROVED OUT-OF-PLANE DAMPING WITH MODEL FOLLOWER

SWING-STRETCH COUPLER

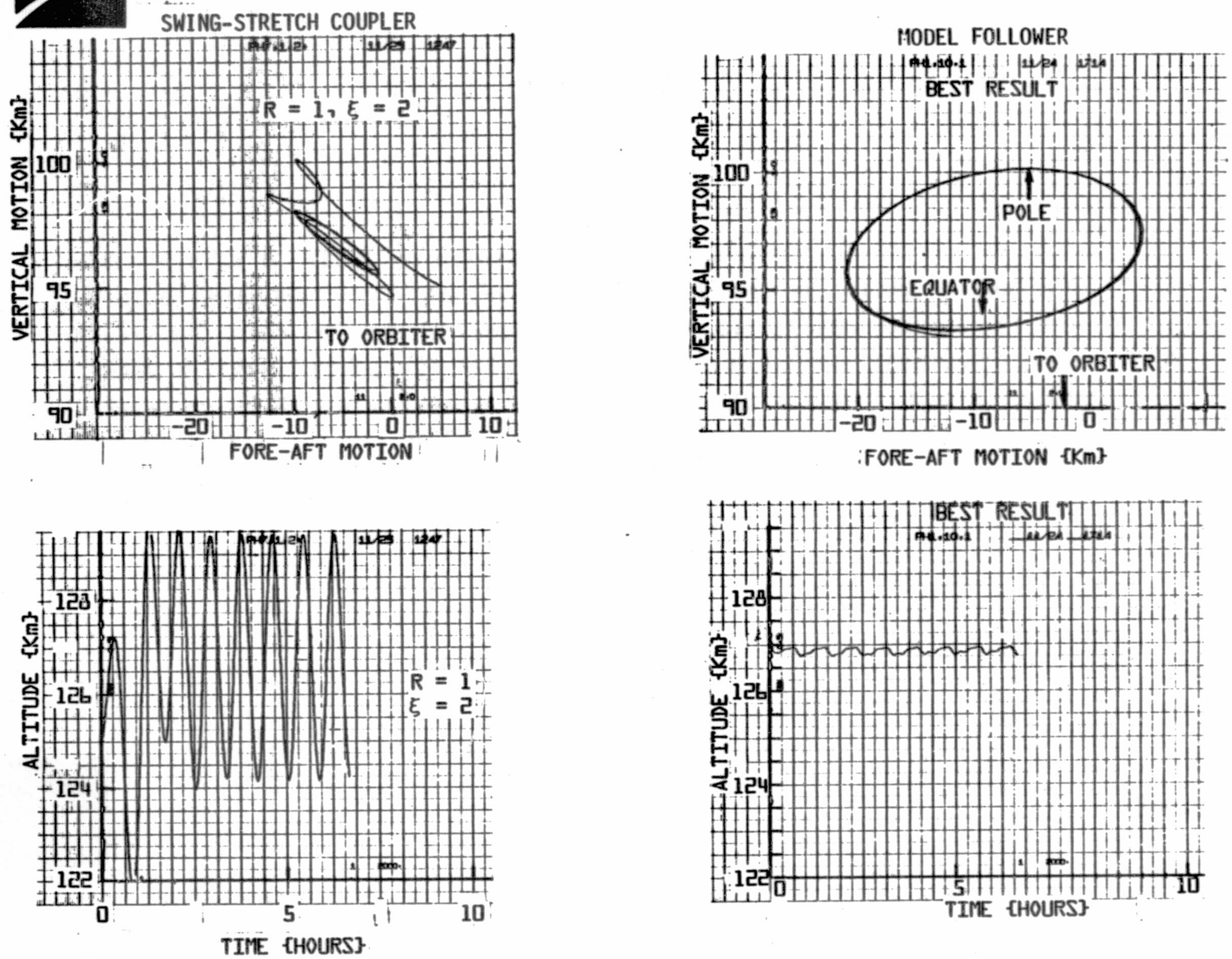


MODEL FOLLOWER
BEST RESULTS



A MODEL FOLLOWER CONTROL LAW RESULTS IN IMPROVED PLANAR CONTROL. MAINTENANCE OF CONSTANT SATELLITE ALTITUDE IN THE PRESENCE OF ATMOSPHERIC DISTURBANCES IS PARTICULARLY GOOD.

MODEL FOLLOWER IMPROVES PLANAR CONTROL



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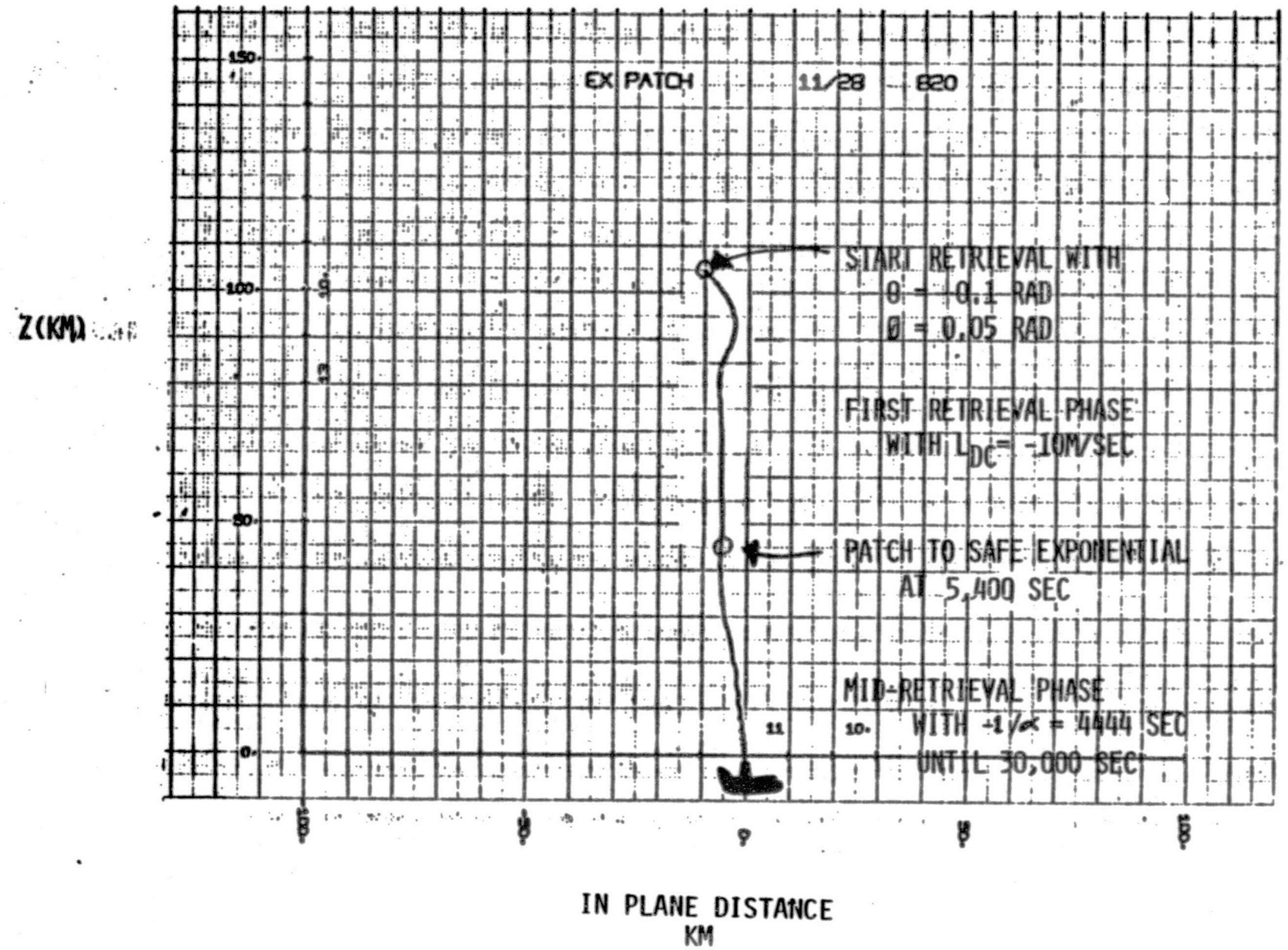
TYPICAL SATELLITE RETRIEVAL, REQUIRING ABOUT 9 HOURS FROM A TETHER LENGTH OF 100 KILOMETERS, ALSO INVOLVES BEGINNING AND TERMINAL PHASES WHERE THE REEL-IN RATE IS PROPORTIONAL TO THE TETHER LENGTH YET REMAINING EXTENDED. DURING THE MID PHASE OF THE RETRIEVAL A CONSTANT REEL-IN RATE OF ABOUT 10 METERS PER SECOND IS USED.

TYPICAL RETRIEVAL PROFILE



TYPICAL SCIENCE ACCOMMODATIONS

SATELLITE COMPONENTS MAY BE LOCATED AND ARRANGED ON THE EQUIPMENT SHELF TO ACCOMMODATE A VARIETY OF EXPERIMENTAL CONFIGURATIONS. TYPICAL IS THE INTERNAL ARRANGEMENT FOR THE ELECTRODYNAMICS EXPERIMENT WHEREIN THE EXPERIMENT COMPONENTS, INCLUDING A DEPLOYABLE ELECTROSTATIC BOOM, ARE LOCATED BENEATH THE SHELF AND SATELLITE HOUSEKEEPING COMPONENTS ARE ON THE OPPOSITE SIDE.

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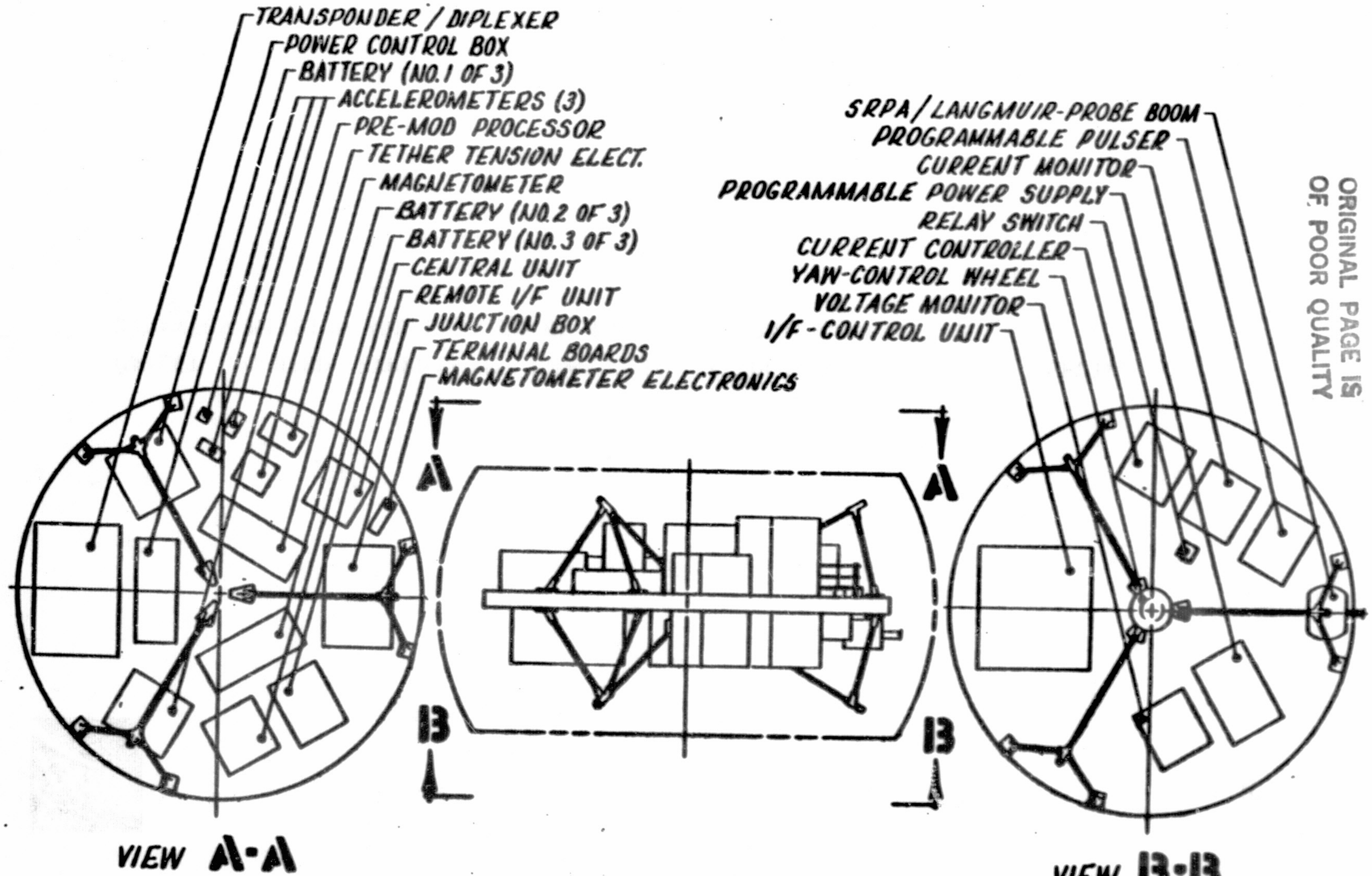
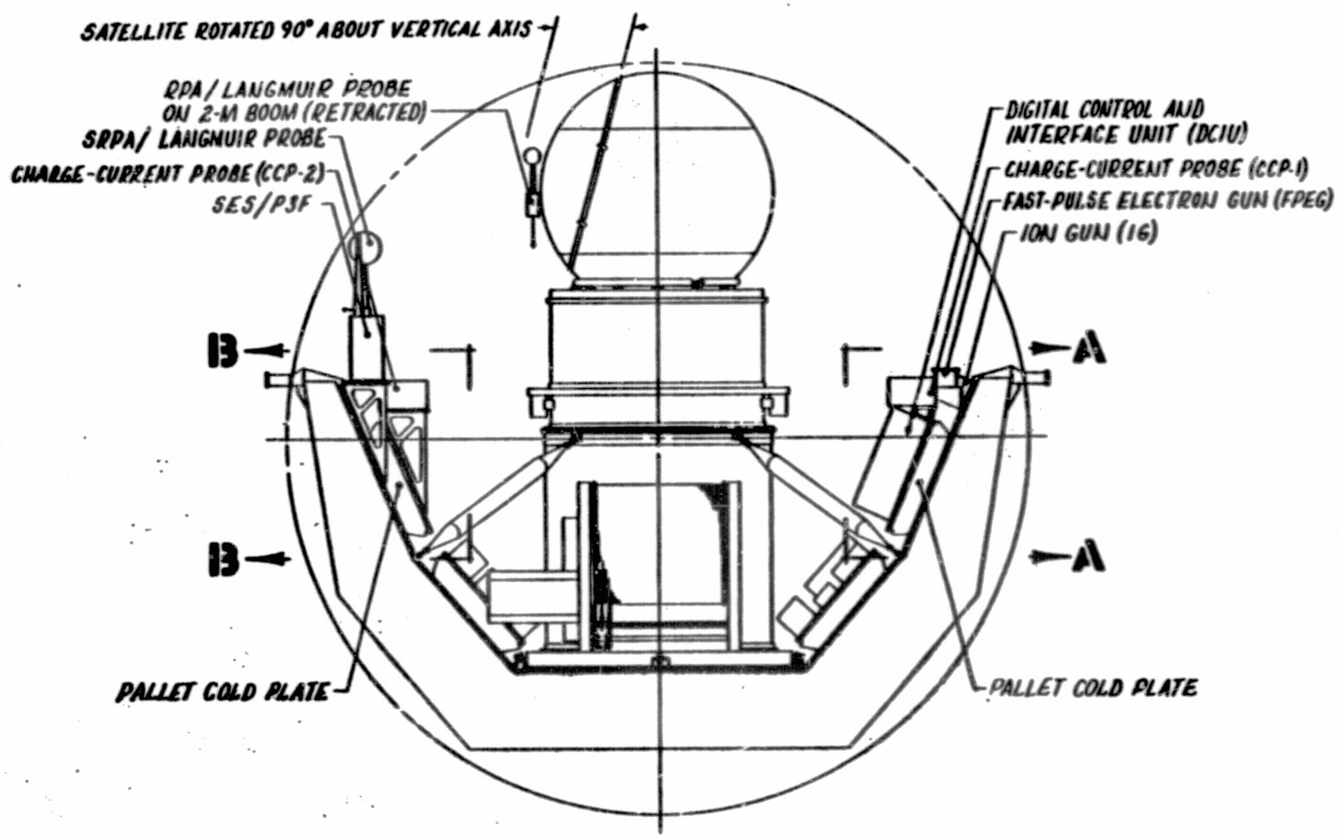
SATELLITE INTERNAL ARRANGEMENT FOR ELECTRODYNAMICS TSS



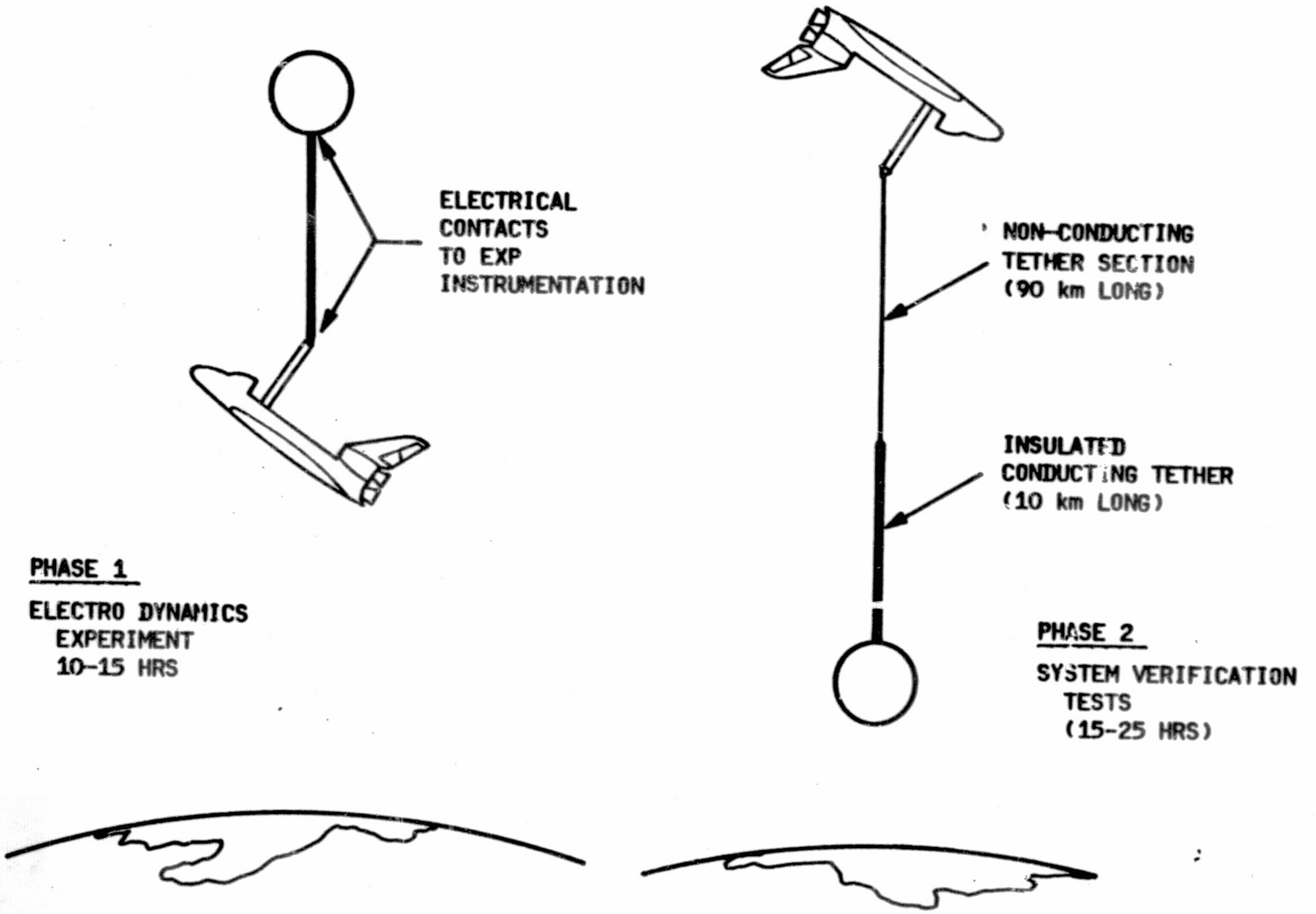
ORIGINAL PAGE IS OF POOR QUALITY

PALLET MOUNTED EXPERIMENT COMPONENTS ASSOCIATED WITH THE ELECTRODYNAMICS MISSION ARE LOCATED ON THE PALLET RAILS.

PALLET-MOUNTED AND SATELLITE-EXTERNAL EQUIPMENT FOR ELECTRODYNAMIC TSS



ELECTRO DYNAMICS MISSION PHASES



PHASE 1

ELECTRO DYNAMICS
EXPERIMENT
10-15 HRS

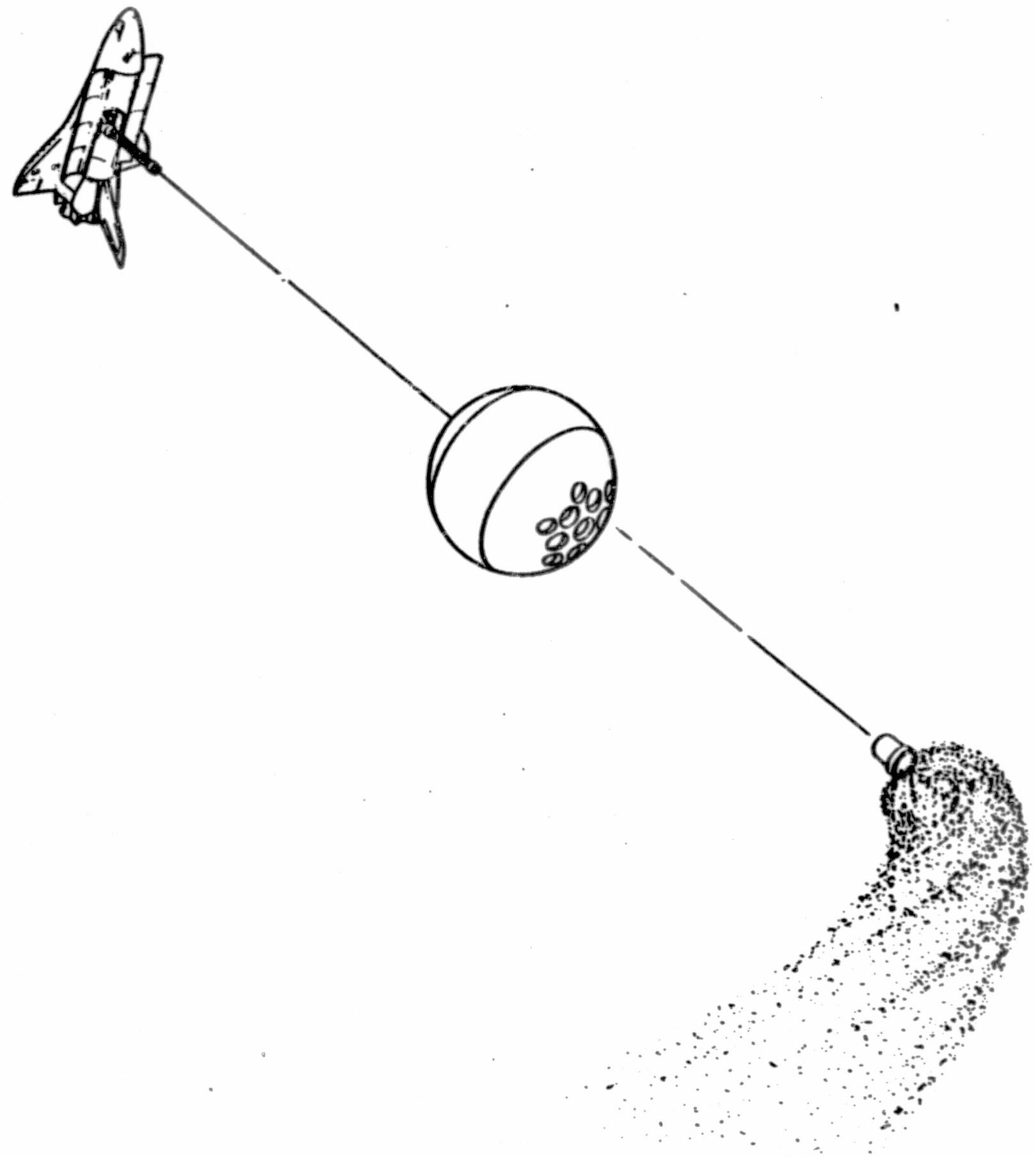
PHASE 2

SYSTEM VERIFICATION
TESTS
(15-25 HRS)

FOR DEPLOYING CHEMICAL MATERIALS USED IN STUDYING ATMOSPHERIC TRANSPORT PHENOMENA, THE SATELLITE IS EQUIPPED WITH INDIVIDUAL CANISTER EJECTION MODULES.

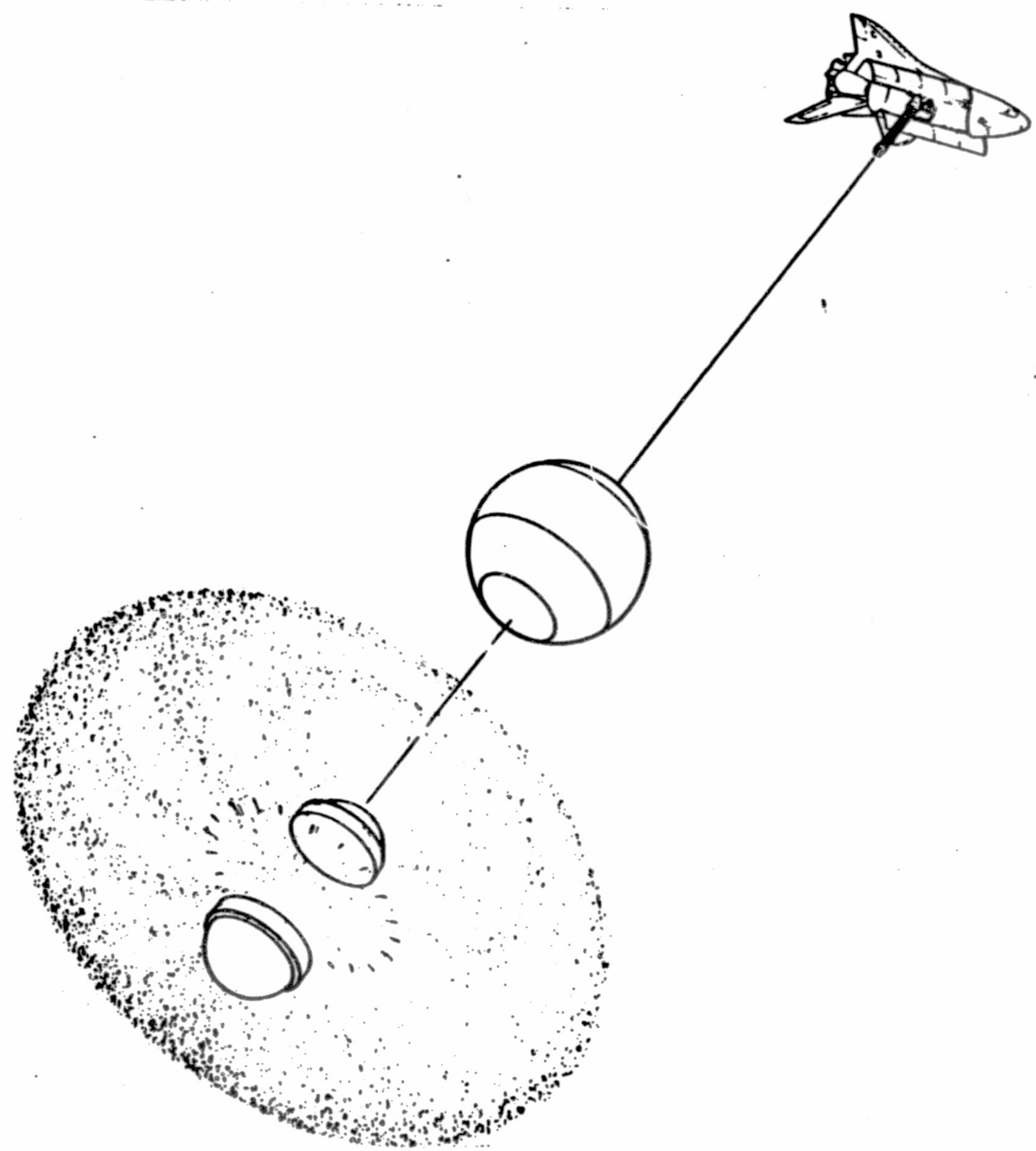
EACH CANISTER IS SPRING EJECTED AND DETONATED AFTER A SUITABLE TIME DELAY IN RESPONSE TO A TIMER LOCATED ON EACH CANISTER.

THERMITE RELEASE CONFIGURATION



A SECOND METHOD FOR RELEASING CHEMICALS USES A SINGLE HIGH PRESSURE GAS CONTAINER EJECTED FROM THE SATELLITE AND DETONATED AT THE DESIRED ALTITUDE.

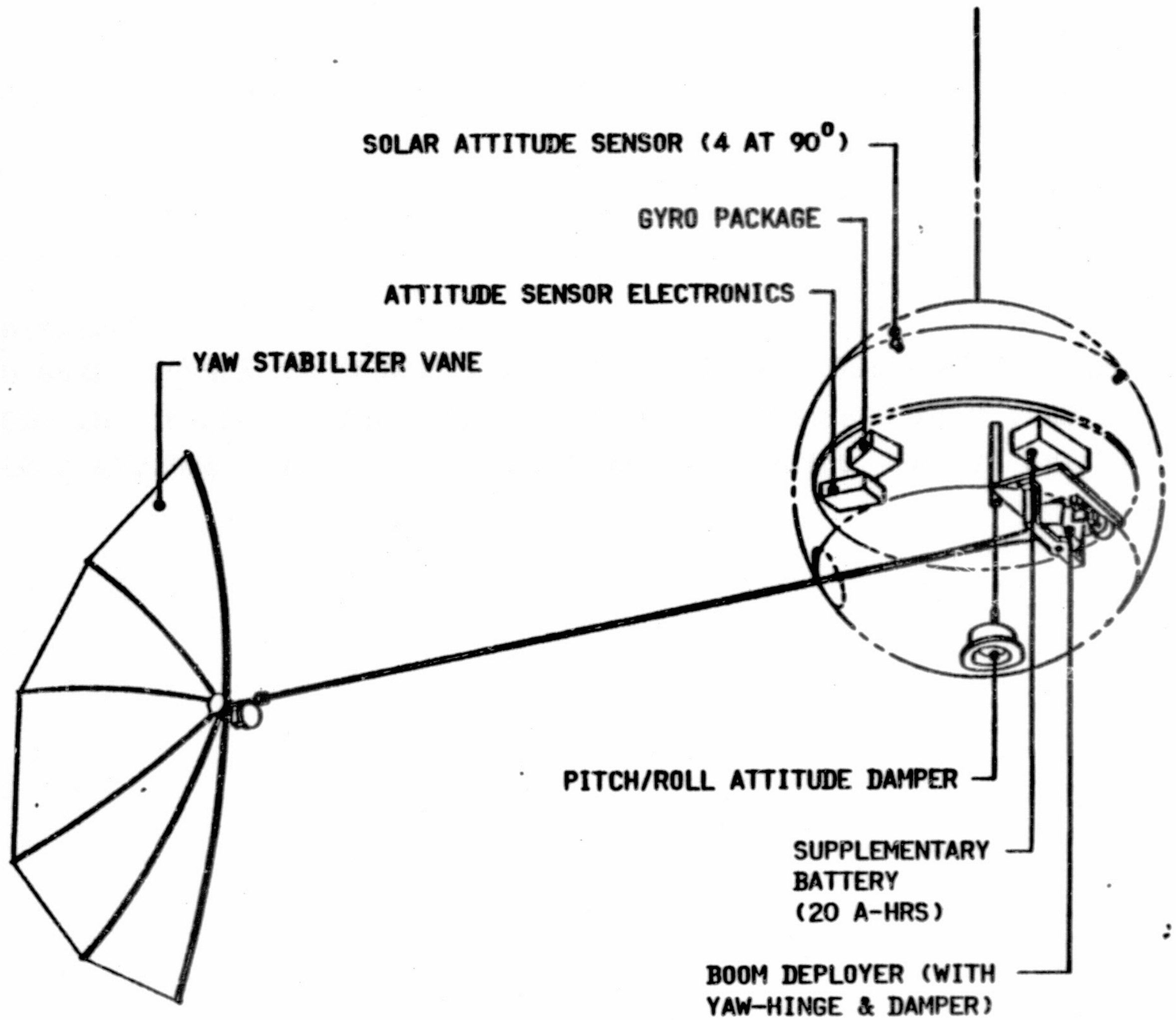
GAS RELEASE CONFIGURATION



TO ACCOMMODATE ATMOSPHERIC EXPERIMENTS THE SATELLITE IS EQUIPPED WITH A STABILIZATION VANE WHICH CONTROLS THE YAW ATTITUDE TO WITHIN 2° OF THE DIRECTION OF FLIGHT. PITCH AND ROLL MOTION IS DAMPED BY A PASSIVE PENDULUM DAMPER.

SATELLITE ATTITUDE IS MEASURED BY RATE GYROS, UPDATED FROM ATTITUDE MEASUREMENTS FROM SOLAR SENSORS.

ATTITUDE CONTROL & DETERMINATION SUBSYSTEM ELEMENTS ATMOSPHERIC MISSION EXPERIMENT COMPLEMENT



SIMULTANEOUS MEASUREMENTS COULD BE MADE BY POSITIONING SEVERAL SATELLITES ALONG THE TETHER. EACH SATELLITE WOULD BE EQUIPPED WITH A SELF-CONTAINED POWER SUPPLY AND COMMUNICATIONS SYSTEM IN ADDITION TO EXPERIMENT INSTRUMENTATION.

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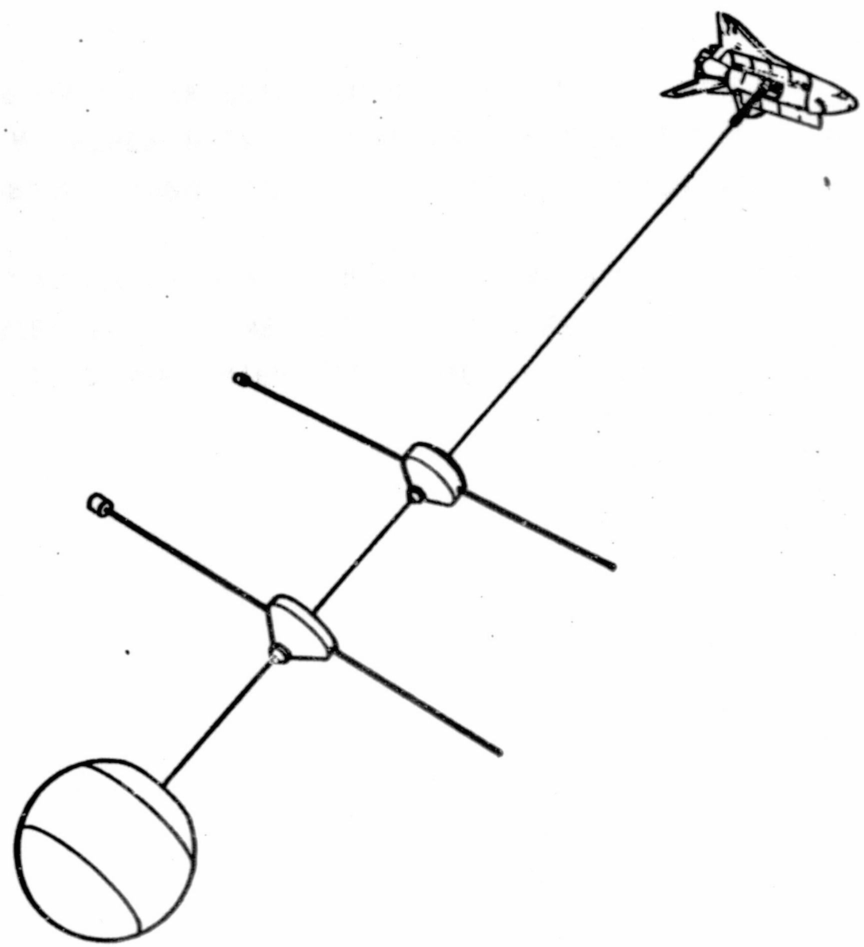
MULTIPLE SATELLITE CONCEPT



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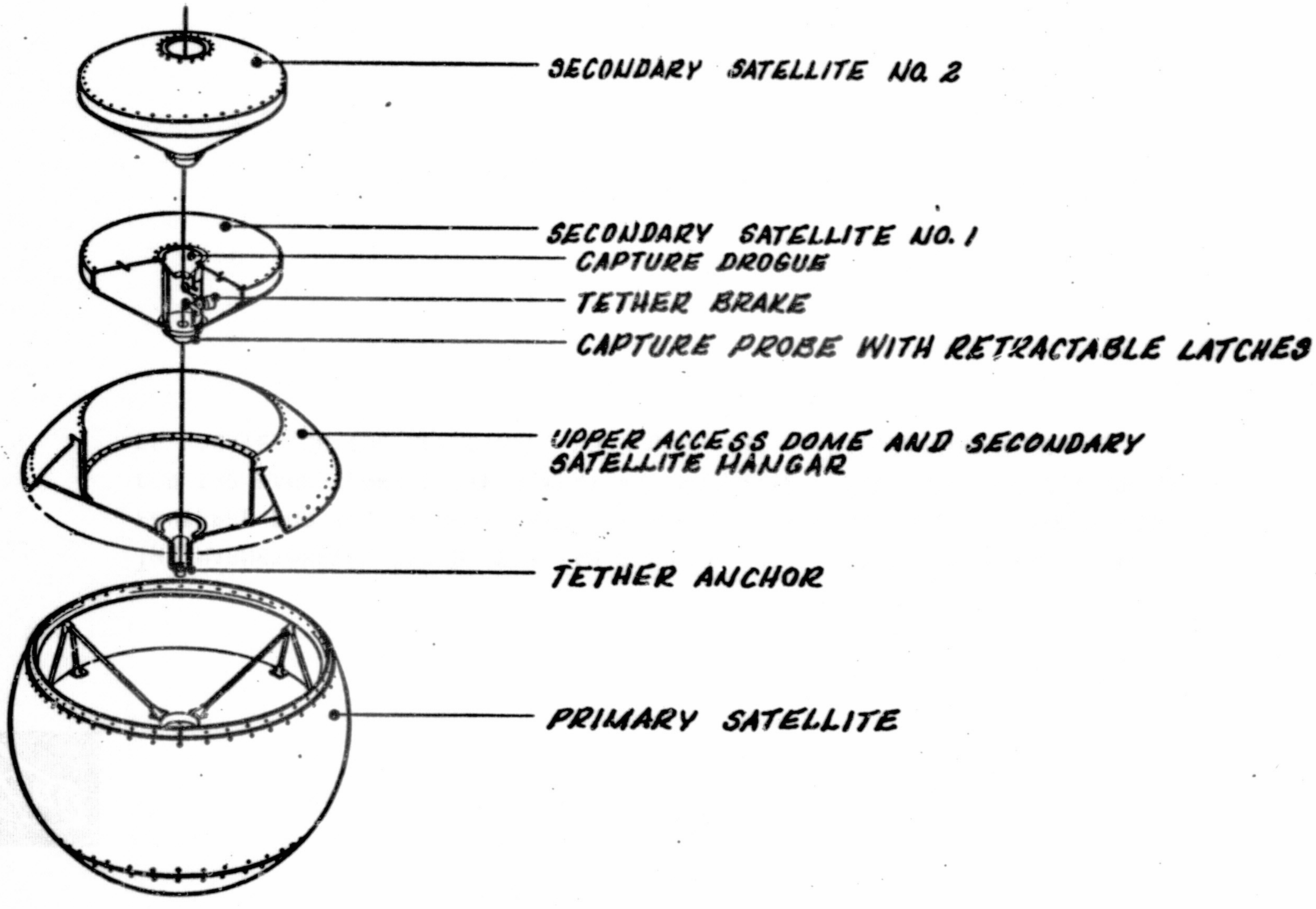
MULTIPLE SATELLITES ARE INTEGRATED INTO THE BASIC SPHERICAL SHAPE OF THE "MOTHER SATELLITE" BY NESTING THE SMALLER UNITS, USING DROGE AND CAPTURE MECHANISMS SIMILAR TO THOSE ON THE MOTHER SATELLITE.

THE TETHER THREADS THRU THE SUB-SATELLITES, EACH ONE OF WHICH IS EQUIPPED WITH A TETHER BREAK MECHANISM FOR LOWERING THE SUBSATELLITE INTO THE MOTHER SATELLITE PRIOR TO RETRIEVAL.

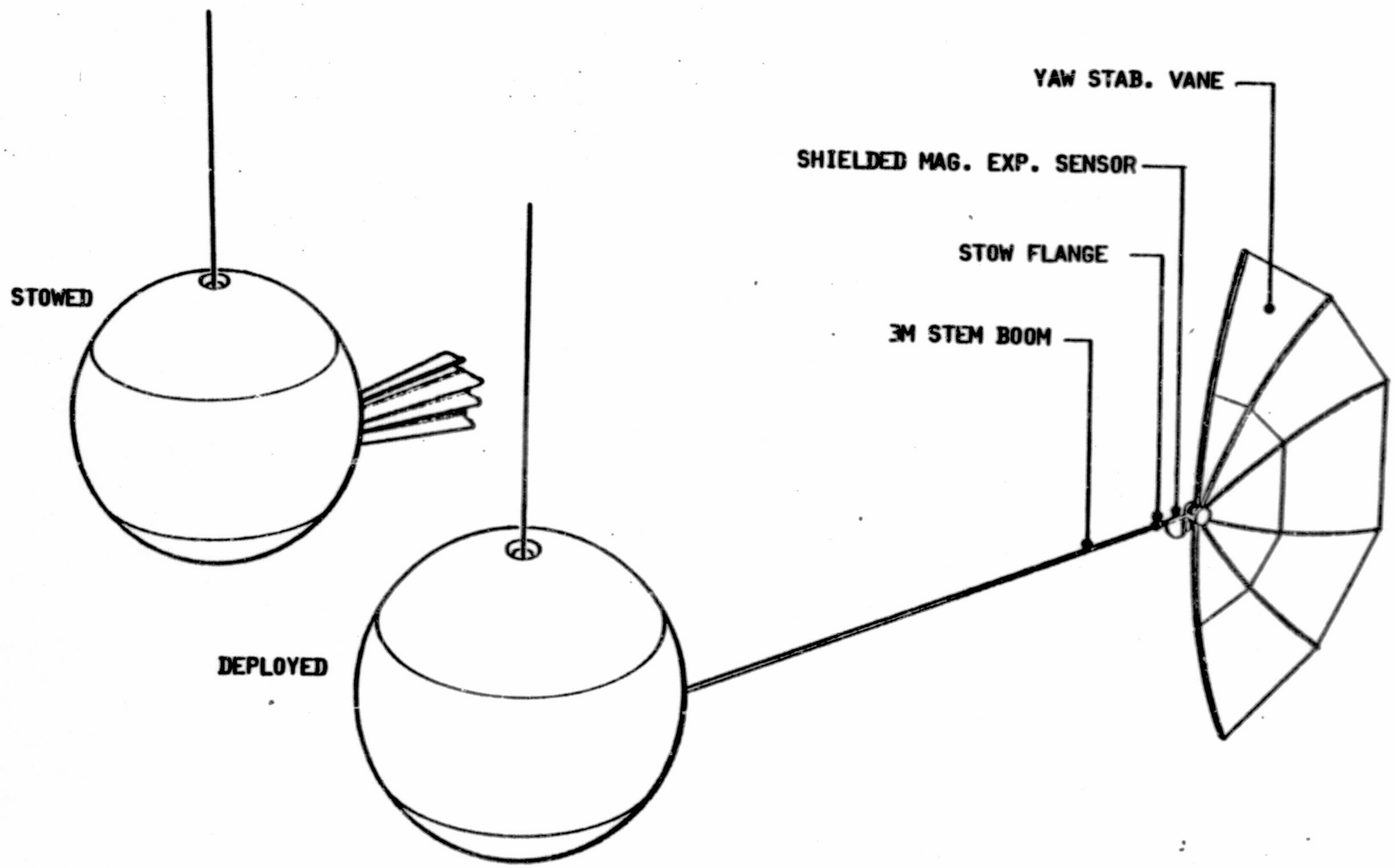
TETHERED SATELLITE ADAPTED TO SECONDARY SATELLITES



THE MAGNETOMETER EXPERIMENT CAN ALSO BE ACCOMMODATED ON A SATELLITE EQUIPPED FOR THE "ATMOSPHERIC" MISSION. POWER AND DATA REQUIREMENTS FOR THE MAGNETOMETER EXPERIMENT ARE MODERATE. THE MAGNETOMETER WOULD BE LOCATED ON THE DEPLOYABLE BOOM NEAR THE STABILIZATION VANE.

F80-10

TSS SPACECRAFT CONCEPTUAL DESIGN ADAPTED FOR "COMBINATION" MISSION EXPERIMENT COMPLEMENT



TSS COST STUDIES

COST STUDIES WERE CONDUCTED TO ASSESS THE SAVINGS IN PROGRAM COSTS WHICH MIGHT BE REALIZED BY REDUCING THE COMPLEXITY OF THE SATELLITE, AND THE ATTENDANT SACRIFICE IN THE VERIFICATION CAPABILITY OF THE SYSTEM.

THE SATELLITE COMPLEXITY CONSIDERED RANGE FROM A COMPARATIVELY SIMPLE PASSIVE "DUMB-BALL" SATELLITE THROUGH VERSIONS HAVING VARIOUS METHODS OF DATA RETRIEVAL, ACTIVE EXPERIMENTS, AND SATELLITE POSITION DETERMINATION.

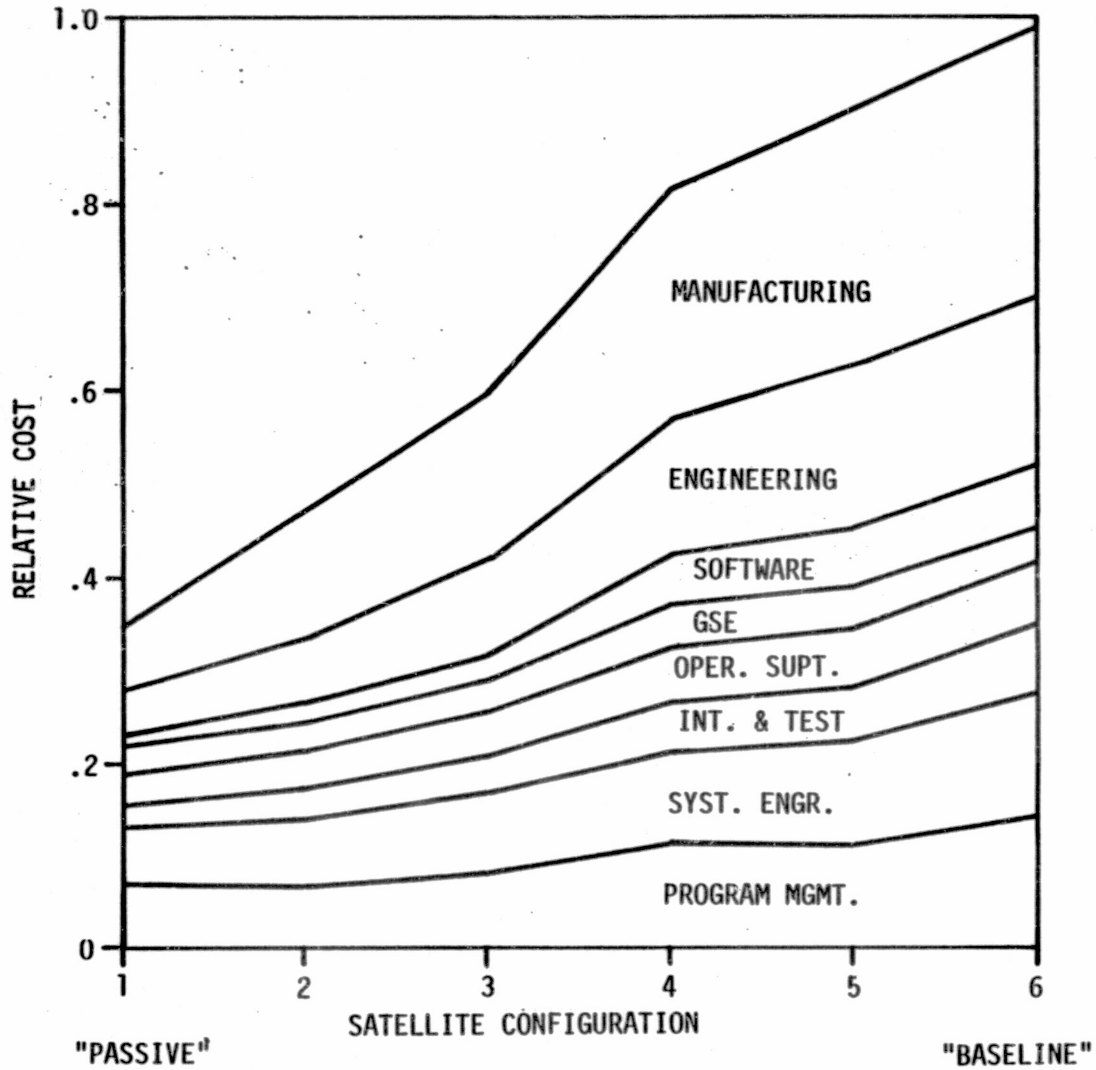
NEARLY ALL OF THE DEPLOYER FUNCTIONS CAN BE VERIFIED USING A SATELLITE OF REDUCED CAPABILITY.

VERIFICATION CAPABILITY FOR VARIOUS SATELLITE CONFIGURATIONS WITH REDUCED CAPABILITY

PASSIVE SATELLITE	RECORDED DATA	REAL-TIME DATA	COMD. & POSITN. DET.	LOW ALT. EXPLORATORY	BASELINE CONFIG.	
1	2	3	4	5	6	
X	X	X	X	X	X	BOOM DEPLOYMENT, SATELLITE SEPARATION, CAPTURE, DOCKING, STOWING
X	X	X	X	X	X	DEPLOYER REELING SYSTEM FUNCTION
22	22	22	100	100	100	TETHER/SATELLITE DYNAMICS AS DETECTED BY SAT POSITION MEASUREMENTS-TETHER LENGTH-KM
135	135	135	130	120	120	SATELLITE THERMAL CONTROL VERIF. MIN ALTITUDE - KM.
					X	QUANTITATIVE VERIFICATION OF SATELLITE ATT. CONTROL PERF.
-	-	PART-IAL	X	X	X	ORBITER/SPACELAB REAL-TIME SATELLITE SUPPORT EFFECTIVENESS
X	X	X	X	X	X	DEPLOYER-SPACELAB MECHANICAL, THERMAL, ELECTRICAL COMPATABILITY

REDUCING THE CAPABILITY OF THE SATELLITE RESULTS IN A CORRESPONDING REDUCTION IN SATELLITE COSTS. HOWEVER THE AFFECT ON TOTAL PROGRAM COSTS IS MODERATE SINCE THE SATELLITE COSTS MAKE UP ONY ABOUT 30% OF THOSE OF THE TOTAL PROGRAM.

SATELLITE COSTS FOR CONFIGURATIONS WITH VARIOUS CAPABILITIES - RELATIVE



PHASE B EXTENSION STUDY TASKS
SUMMARY CONCLUSIONS

EXTENSION STUDY - SUMMARY CONCLUSIONS

1100 - DYNAMICS ANALYSIS

- RETRIEVAL TIME CAN BE SHORTENED TO 7 HOURS FROM 11 HOURS BY EXECUTING ORBITER ΔV MANEUVERS AT APPROPRIATE INTERVALS DURING RETRIEVAL.
- FINAL RETRIEVAL CAN BE ACCELERATED, AND EXECUTED USING TENSION LEVELS SUBSTANTIALLY ABOVE CONTROL LIMITS BY EXECUTING ORBITER ATTITUDE MANEUVERS AS SATELLITE APPROACHES DOCKING RING.
- SUCCESSFUL DOCKING OCCURS FOR MISS DISTANCES OF $\pm$ 1.2 METERS BY USING MODIFIED TENSION CONTROL LAW DURING DOCKING PHASE.

EXTENSION STUDY - SUMMARY CONCLUSIONS (CONT'D)

1200 - SOFTWARE REQUIREMENTS DEFINITION

- ALL SPECIAL-PURPOSE SOFTWARE FUNCTIONS ARE CONFINED TO THE TSS DEDICATED PROCESSOR.
- ORBITER AND SPACELAB SOFTWARE FUNCTIONS ARE RESTRICTED TO DATA AND COMMAND MULITPLEXING, CONVERSION TO PHYSICAL USES, DISPLAY GENERATION AND NAVIGATIONAL CALCULATIONS NORMALLY PERFORMED BY THE ORBITER.

EXTENSION STUDY - SUMMARY CONCLUSIONS (CONT'D)

1300 - TETHER MATERIALS EVALUATION

- KEVLAR 29 IS THE BEST CHOICE OF TETHER MATERIAL FOR THE VERIFICATION MISSION. PRODUCTION AND SPLICING TECHNIQUES ARE WELL ESTABLISHED. IT CAN ALSO BE USED FOR INSULATED CONDUCTING TETHERS.

1400 - AUTONOMOUS - MOUNT (UNIQUE PALLET)

- A PALLET MOUNT DESIGNED SPECIFICALLY FOR THE TSS, HAS THE ADVANTAGE OF LOWER LAUNCH COSTS, GREATER STRUCTURAL RIGIDITY AND BETTER TETHER ROUTING.

EXTENSION STUDY - SUMMARY CONCLUSIONS (CONT'D)

1500 - COST OPTIMIZATION

- REDUCING SATELLITE CAPABILITY RESULTS IN ONLY A MODEST REDUCTION IN TOTAL PROGRAM COSTS.

- DEPLOYER REELING RATES CAN BE REDUCED TO ABOUT 10 M/SEC WITHOUT SERIOUSLY INCREASING DEPLOYMENT OR RETRIEVAL TIMES. THIS ENABLES USE OF SMALLER MOTORS, DRIVE CIRCUITRY AND POWER CONVERTERS.

EXTENSION STUDY – SUMMARY CONCLUSIONS (CONT'D)

1600 - SPECIAL STUDIES

- THE SATELLITE-TO-ORBITER DATA RATE CAN BE INCREASED FROM THE BASELINE VALUE OF 8 KBPS UPWARD TO 256 KBPS BY THE USE OF DIRECTIONAL ANTENNAS AND SPECIAL EQUIPMENT MOUNTED ON THE DEPLOYER.

- MOST PROMISING METHOD OF REAL TIME SATELLITE POSITION DETERMINATION IS THE USE OF THE ORBITER RENDEZVOUS RADAR. THE SATELLITE IS EQUIPPED WITH A RETRO REFLECTOR TO ENHANCE ITS RADAR CROSS-SECTION.

- ALTERNATE METHOD FOR MID & LONG-RANGE, REAL TIME POSITION DETERMINATION WOULD USE ORBITER ATTITUDE DATA WHILE FLYING IN "DRIFT" MODE.

- SATELLITE POSITION NEAR THE ORBITER (LESS THAN ABOUT 400 METERS) WILL BE DETERMINED USING CLOSED CIRCUIT TV CAMERAS MOUNTED ON THE PALLET.

EXTENSION STUDY - SUMMARY CONCLUSIONS (CONT'D)

2100 - ELECTRODYNAMICS EXPERIMENT ACCOMMODATION

- REQUIRES "UPWARD" DEPLOYMENT, ADVANCES IN CONDUCTING TETHER DEVELOPMENT, AND EXPERIMENT EQUIPMENT MOUNTED ON BOTH SATELLITE AND DEPLOYER.

2200 - CHEMICAL RELEASE EXPERIMENT ACCOMMODATION

- MODEST AMOUNTS OF EITHER THERMITE OR GASEOUS CHEMICALS COULD BE DEPLOYED. SOME ADDITIONAL SAFETY AND OPERATIONAL PLANNING REQUIRED.

EXTENSION STUDY - SUMMARY CONCLUSIONS (CONT'D)

2300 - ATMOSPHERIC EXPERIMENT ACCOMMODATION

- COMPLEMENT OF FOUR INSTRUMENTS REQUIRES INCREASE OF STORED ELECTRICAL ENERGY TO 100 AMP. HOURS (FROM 60), ADDITIONAL, MORE PRECISE ATTITUDE CONTROL AND DETERMINATION SUBSYSTEMS.

2400 - MULTIPLE SATELLITE - EXPERIMENT ACCOMMODATION

- FEASIBLE IN CONCEPT TO ACCOMMODATE TWO OR THREE SATELLITES SPACED ALONG TETHER. DEPLOYMENT COMPLEXITY AND COST SUBSTANTIALLY INCREASED OVER THAT OF BASELINE SYSTEM.

EXTENSION STUDY - SUMMARY CONCLUSIONS (CONT'D)

2500 - MAGNETOMETER EXPERIMENT ACCOMMODATION

- OPERATED IN SCALER MODE, IS THE SIMPLEST OF ALL EXPERIMENTS TO ACCOMMODATE MODEST POWER AND SPACE REQUIREMENTS; WOULD LIKE TO FLY AT LOWER ALTITUDES.

2600 - "COMBINATION" MISSION - EXPERIMENT ACCOMMODATION

- EXPERIMENT COMPLEMENT INCLUDES BOTH ATMOSPHERIC (2300) AND MAGNETOMETER (2400) EXPERIMENTS. "ON-STATION" OPERATION OF 23 HOURS REQUIRES 100 AMP. HOURS STORED ENERGY (AT 28V), PRECISE ATTITUDE CONTROL AND DETERMINATION.

PHASE B STUDY TASKS/RESULTS

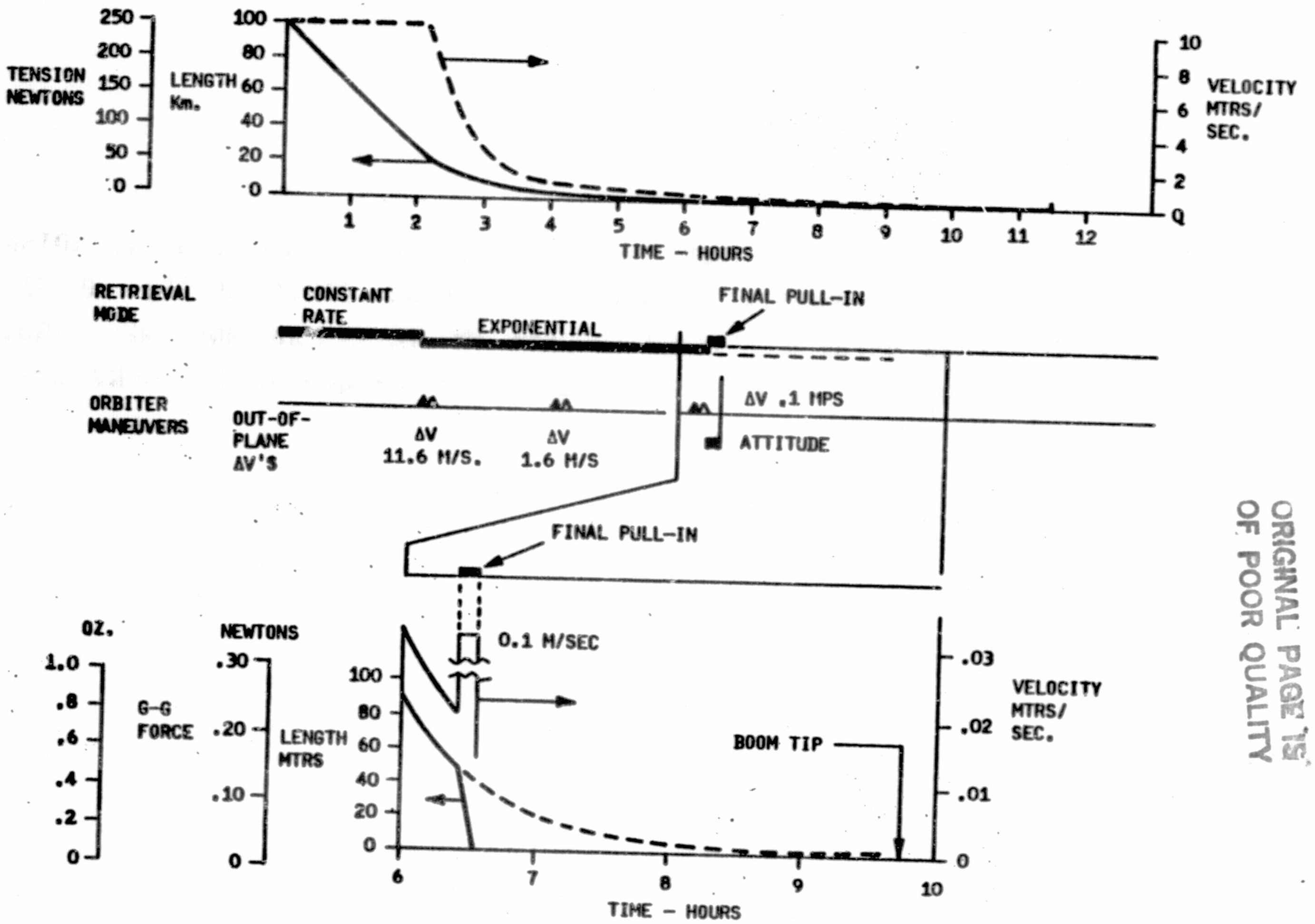
1100 -DYNAMICS ANALYSIS

- REVISE TETHER SIMULATION TO INCLUDE EFFECT OF BOOM MOTION
- STUDY FINAL RETRIEVAL PHASE
- SIMULATE AND ANALYZE BEHAVIOR OF DOCKING MECHANISM

EXECUTION OF ORBITER DELTA V MANEUVERS DURING MAIN PHASE OF RETRIEVAL MARKEDLY DECREASES THE SATELLITE LIBRATION AND SHORTENS RETRIEVAL TIME FROM 13 DOWN TO ABOUT 9 HOURS.

FURTHER DECREASE IN RETRIEVAL TIME TO ABOUT 6-1/2 HOURS IS ACHIEVED BY CONTROLLING THE ATTITUDE OF THE ORBITER DURING THE FINAL PULL IN PHASE WHICH IS EXECUTED AT A RATE OF ABOUT 1/10 OF A METER PER SECOND. THIS ALSO MINIMIZES THE NEED TO CONTROL TETHER TENSION LEVELS AT LOW VALUES.

RETRIEVAL TIMELINE & PROFILES - 500 KG SATELLITE



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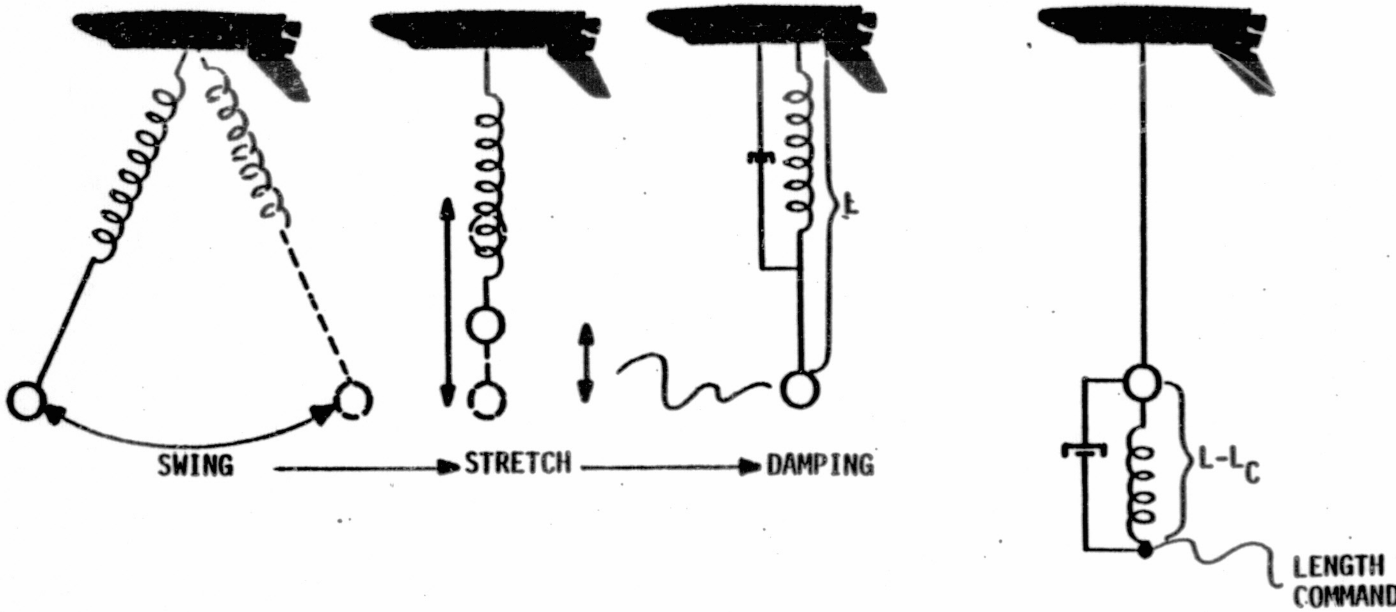
DYNAMICS ANALYSIS PERFORMED DURING THIS STUDY EXTENSION WAS BASED ON PREVIOUS WORK DONE DURING THE MAIN STUDY PHASE. A BRIEF REVIEW OF THE RESULTS OF THE PREVIOUS STUDIES AND THE RELATIONSHIP TO THE STUDY EXTENSION TASKS IS GIVEN IN THE FOLLOWING PAGES.

DYNAMICS SUMMARY

- REVIEW BASD CONTROL CONCEPTS
- STEADY STATE PLANAR CONTROL ACCOMPLISHMENTS
  CONSTANT HEIGHT - DENSITY - HEATING CAPABILITY ADDING LINEAR OPTIMAL PLANAR ANGLE FEEDBACK
- STEADY STATE OUT-OF-PLANE CONTROL ACCOMPLISHMENTS-DAMPING SMALL ANGLES TWENTY TIMES FASTER-PLANAR ORBITER ΔV CAN REVERSE BUILD-UP
- DEPLOYMENT TIME SHORTENED TO 4.8 HOURS (WITH A CONSERVATIVE 10M/SEC REELING RATE LIMIT)
- RETRIEVAL IMPROVEMENTS
  CONSERVATIVE RATE LIMITING APPROACH
  PURE EXPONENTIAL TIME REDUCED TO 13 HOURS
  ORBITER OUT-OF-PLANE ΔV's REDUCE TIME TO 8 HOURS
  BOOM POINTING DURNING FINAL PULL-IN REDUCES TIME TO 6 HOURS

STEADY STATE CONTROL CONCEPTS



TUNED SWING-STRETCH COUPLER

MODEL FOLLOWER

STEADY STATE CONTROL ACCOMPLISHMENTS

- OBSERVATIONS ON PLANAR COUPLING (SHIFT OF INDEPENDENT L AND θ FREQUENCIES)
- STABILITY CONDITION FOR UNREALISTIC SPHERICAL ATMOSPHERE
- PERTURBATIONS OF AN OBLATE ROTATING ATMOSPHERE
- DEVELOP A NEW ADAPTIVE MODEL FOLLOWING TYPE CONTROLLER THAT PERMITS:

  (1) OPERATING SATELLITE AT CONSTANT ALTITUDE/DENSITY

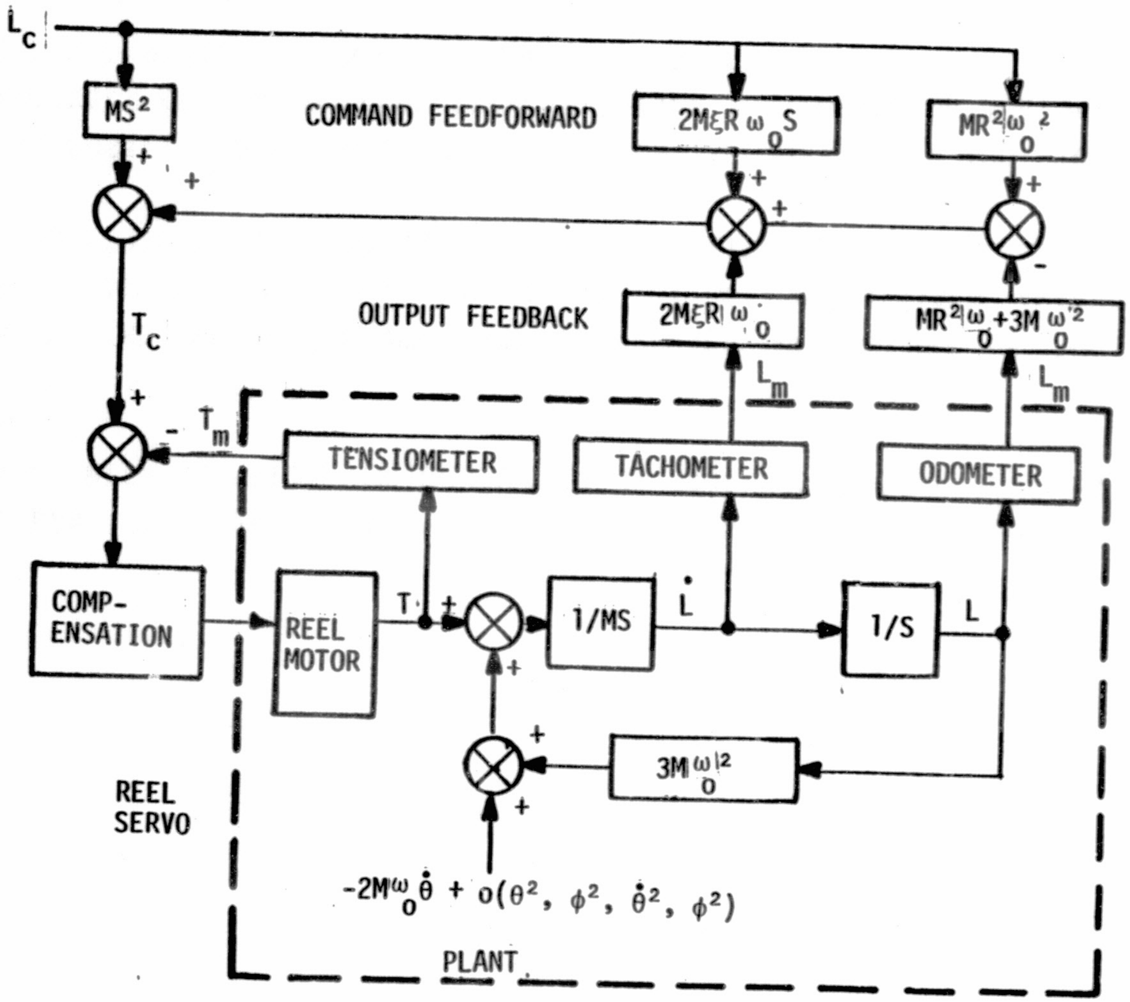
  (2) DAMPING SMALL ϕ 20 TIMES FASTER THAN FOR BEST TUNING OF EXISTING SWING-STRETCH COUPLER (VERIFICATION THAT THE CONTROLLER WORKS WELL WITH AIR DRAG.)

- SHOW THAT APPROPRIATELY PHASED PLANAR ORBITER BURN CAN REVERSE ϕ BUILD-UP CAUSED BY ROTATING ATMOSPHERE UNDER AN ECCENTRIC SHUTTLE ORBIT
- SHOW THAT OPTIMAL FULL-STATE FEEDBACK BASED ON LINEARIZED PLANAR EQUATIONS CAN IMPROVE PLANAR DAMPING
- SHOW THAT $\dot{\phi}^2$ FEEDBACK CAN ALSO IMPROVE OUT-OF-PLANE DAMPING OVER THAT ACHIEVABLE BY TUNING ALONE.

SYMBOL DEFINITIONS RELATIVE TO THE DYNAMICS ANALYSIS ARE AS FOLLOWS:

Φ	=	ANGLE MEASURED PERPENDICULAR TO THE ORBIT PLANE (OUT OF THE ORBIT PLANE) INDICATING POSITION OF THE SATELLITE RELATIVE TO NADIR.
Θ	=	ANGLE MEASURED IN THE ORBIT PLANE INDICATING POSITION OF THE SATELLITE RELATIVE TO NADIR.
L_C	=	LENGTH COMMAND AS A FUNCTION OF TIME.
M	=	MASS OF THE SATELLITE.
S	=	LAPLACE TRANSFORM OPERATOR.
η	=	MODEL FOLLOWER DAMPING CONSTANT.
R	=	MODEL FOLLOWER GAIN COEFFICIENT.
ω_0	=	ORBITAL FREQUENCY.
T_C	=	TENSION COMMAND GENERATED BY THE CONTROL LAW.
$\dot{\Phi}$ & $\dot{\Theta}$	=	TIME DERIVATIVES OF THE SATELLITE ANGULAR POSITION COORDINATES.
L_M	=	MEASURED TETHER LENGTH.

TUNING A COMMAND-LENGTH MODEL-FOLLOWER

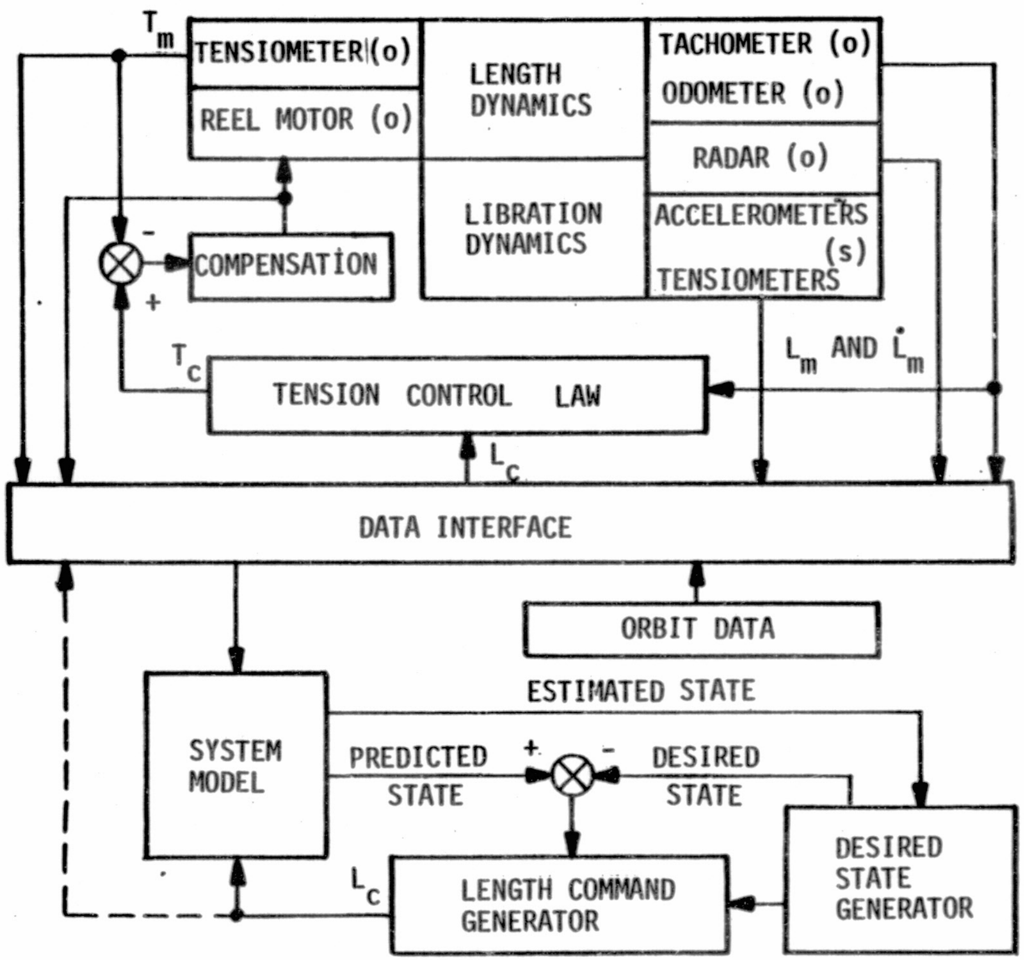


CONTROL LAW LOGIC IS INCORPORATED IN THE ON-BOARD DEPLOYER DEDICATED PROCESSOR, WITH COEFFICIENTS INSERTABLE BY GROUND OR ON-BOARD OPERATOR COMMAND.

CHANGES IN THE ACTUAL LENGTH COMMAND PROFILE AND VALUES OF "MODEL FOLLOWING" COEFFICIENTS ARE CALCULATED AT A GROUND-BASED ANALYSIS CENTER AND PERIODICALLY TRANSMITTED TO THE ORBITER.

SATELLITE POSITION DATA IS TRANSMITTED FROM THE ORBITER TO THE GROUND-BASED ANALYSIS CENTER TO ALLOW NEAR REAL-TIME MONITORING OF THE SATELLITE TETHER DYNAMICS DURING DEPLOYMENT AND RETRIEVAL.

PERIODIC ADAPTATION OF THE MODEL-FOLLOWER COMMAND



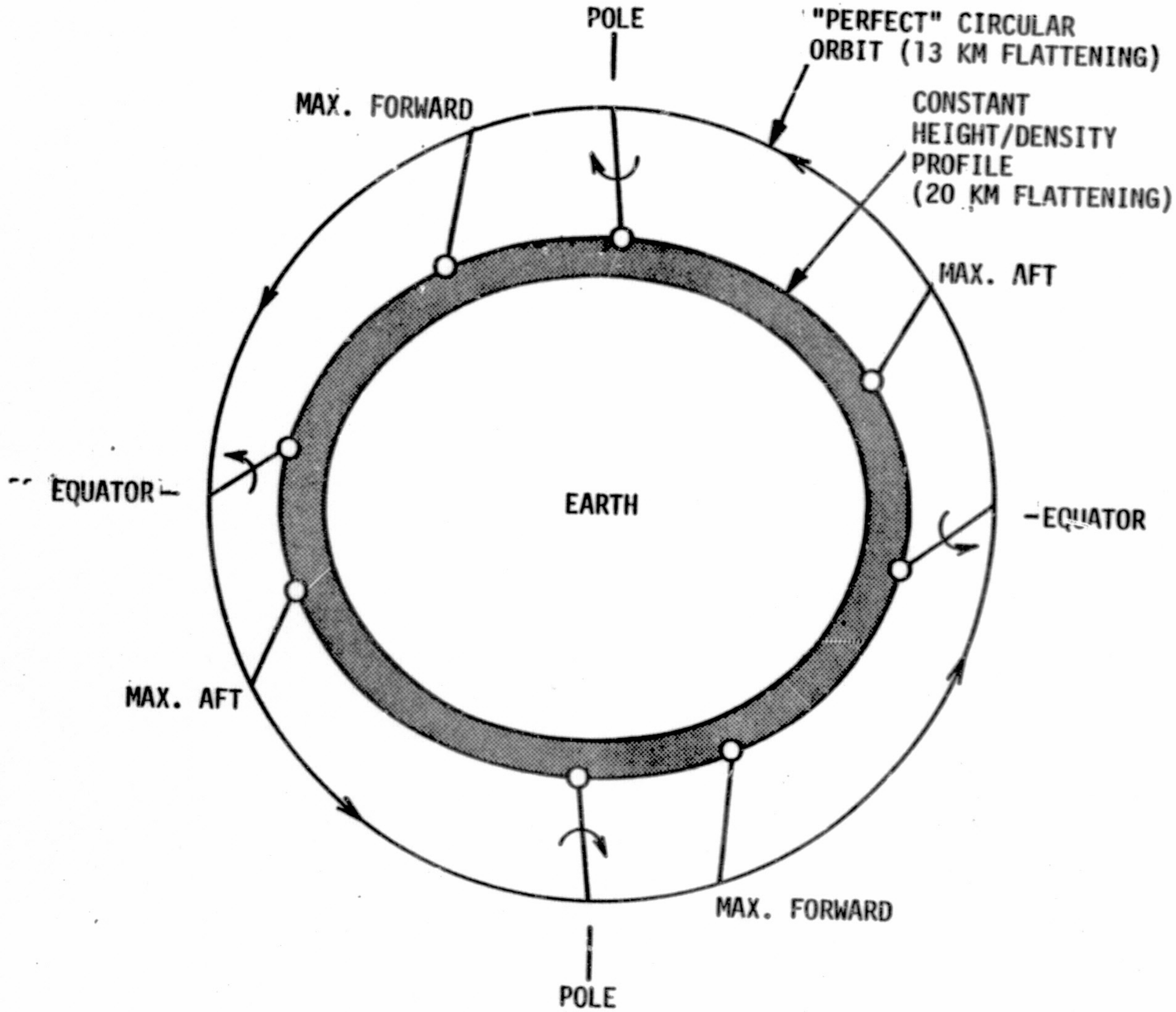
ADVANTAGES AND DISADVANTAGES OF MODEL FOLLOWING

THE SIMPLEST CONCEPT OF USING A "TUNED SWING-STRETCH COUPLER" TO CONTROL LIBRATION MUST BE MODIFIED IN A RELATIVELY SIMPLE WAY TO PRODUCE THE "COMMANDED-LENGTH MODEL FOLLOWER" THAT WE PREFER FOR SEVERAL CONTROL PHASES. ADVANTAGES AND DISADVANTAGES OF THE MODEL FOLLOWER ARE:

- ADDITIONAL MEASUREMENTS ARE NEEDED BUT ONLY TO PERIODICALLY ESTABLISH THE AMPLITUDE AND/OR PHASE OF θ AND/OR ϕ (CLOSED-LOOP FEEDBACK OF SWING STATES APPEARS TO BE AN UNNECESSARY COMPLICATION BUT WE STUDIED LINEAR-OPTIMAL PLANAR AND NON-LINEAR ENHANCED-COUPLING OUT-OF-PLANE CONTROLLERS).
- ADDITIONAL COMPUTATION IS NEEDED BUT UPDATE RATES ARE VERY LOW.
- MEASUREMENT AND COMMAND ERRORS MUST BE SMALL ENOUGH TO KEEP PHASE ERRORS SMALL.
- PERFORMANCE APPEARS DRAMATICALLY BETTER THAN FOR THE BASIC SWING-STRETCH COUPLER WHICH REACTS TO AND CANNOT ANTICIPATE LARGELY PREDICTABLE PERTURBATIONS.
- OUT-OF-PLANE IS ONLY APPLIED WHEN NEEDED SO ϕ-DRIVEN STRETCHING DOES NOT INTRODUCE ADDITIONAL DIRECT MOTION OR θ PERTURBATIONS.

ADVANTAGES OF THE "MODEL FOLLOWER" METHOD OF CONTROL ARE GRAPHICALLY DEMONSTRATED BY THE ABILITY OF THE SYSTEM TO MAINTAIN A CONSTANT ORBITAL ALTITUDE BY ALLOWING THE SATELLITE TO SWING FORE AND AFT IN CONCERT WITH THE VARIATIONS IN ATMOSPHERIC DENSITY.

CONSTANT HEIGHT PROFILE



CONTROL LIMITATION OF THE TUNED COUPLER WITH OBLATE ATMOSPHERE

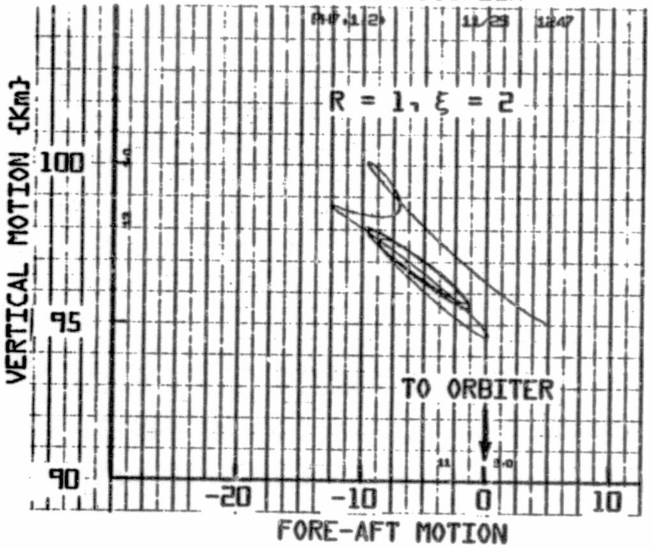
- THE TSSC CANNOT BE TUNED TO PROVIDE REASONABLE HEIGHT CONTROL. THE SATELLITE CAN BE VIEWED AS BOUNCING OFF CONSECUTIVE EQUATORIAL BULGES.
- GOOD LENGTH CONTORL IS POSSIBLE.

IMPROVED MODEL FOLLOWER WITH RELATIVE DAMPING

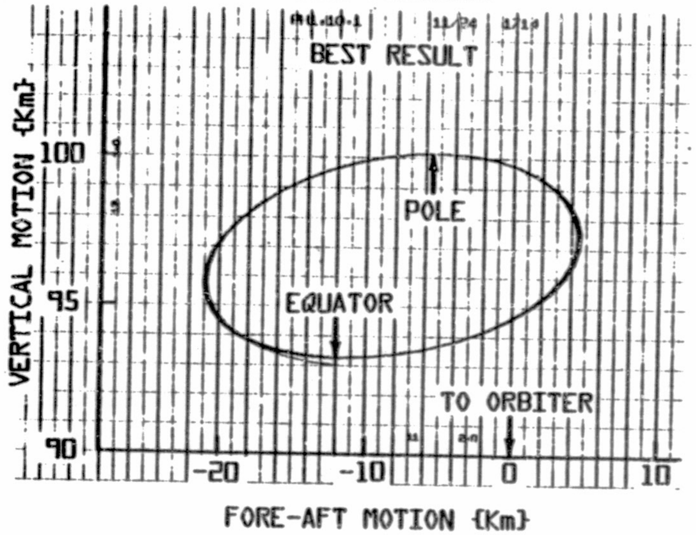
- SURPRISINGLY GOOD HEIGHT CONTROL IS FEASIBLE WITH ACCURATE LENGTH MODULATION INCORPORATING ONLY SECOND AND FOURTH HARMONICS OF ORBIT RATE ($\pm$100M OUT OF $\pm$3500M RELATIVE OBLATENESS).
- MODERATE ERRORS DO NOT PREVENT REASONABLE HEIGHT CONTROL.
- IT IS NECESSARY TO KNOW ORBIT PARAMETERS AND TO DETERMINE PERIODICALLY THE IN-PLANE SWING AMPLITUDE AND PHASE TO IMPLEMENT THIS CONTROL.

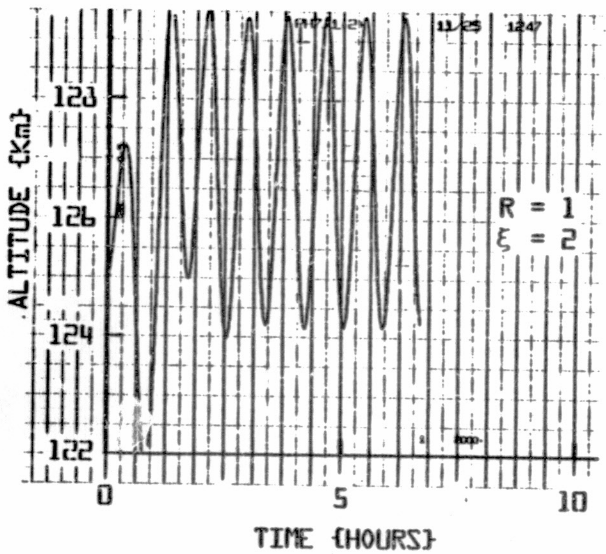
MODEL FOLLOWER IMPROVES PLANAR CONTROL

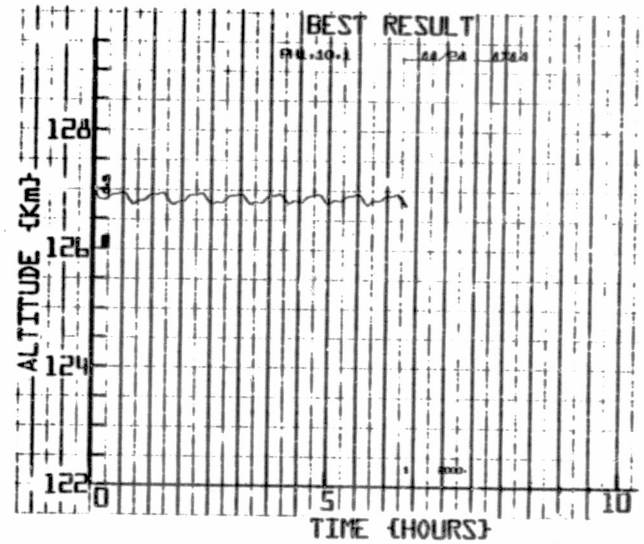
SWING-STRETCH COUPLER



MODEL FOLLOWER



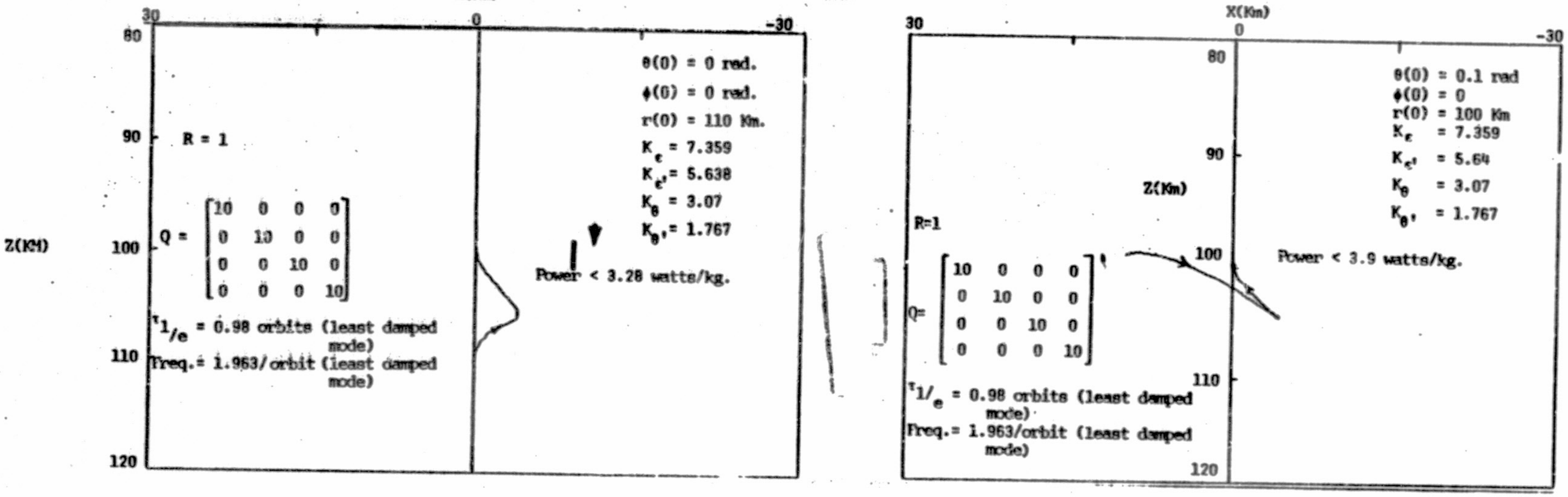




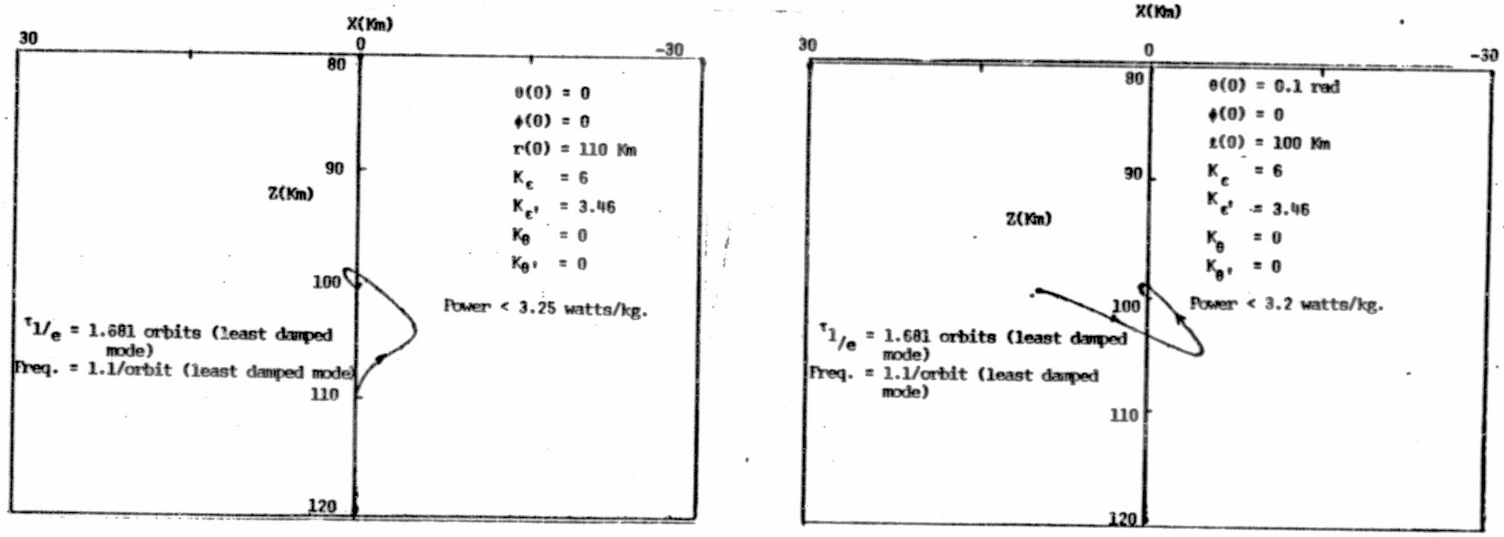
CLASSICAL FEEDBACK CONTROL THEORY WAS ALSO APPLIED TO THE PROBLEM OF TETHER DYNAMICS WITH THE RESULT THAT OPTIMAL FEEDBACK METHODS CAN ALSO BE USED TO REDUCE SATELLITE LIBRATION MOTION.

LINEAR-OPTIMAL LIBRATION FEEDBACK IMPROVES PLANAR DAMPING (See 11-30-78 Review)

LENGTH CHANGE {SIDE VIEW} | LIBRATION DECAY {SIDE VIEW}



OPTIMAL FULL STATE {PLANAR} FEEDBACK

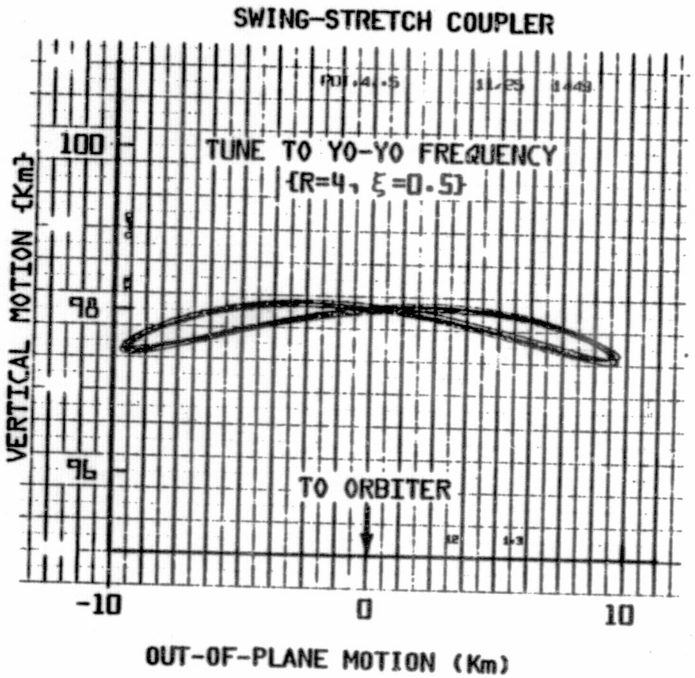


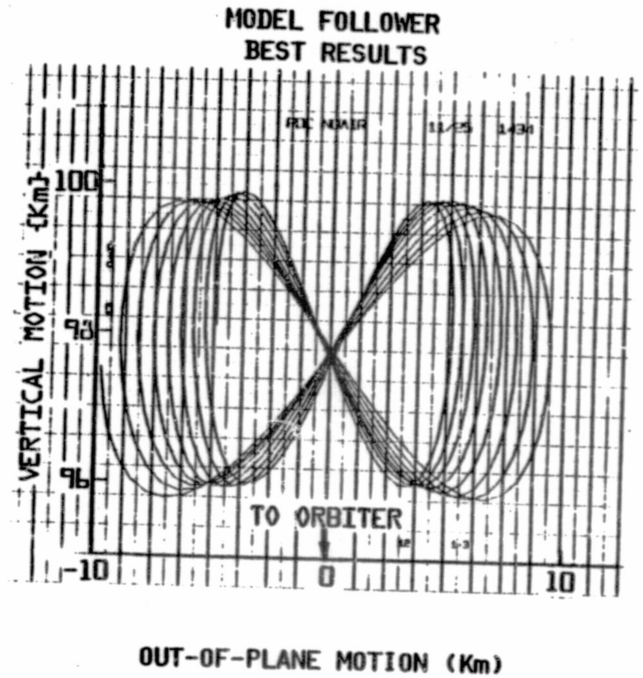
LENGTH AND LENGTH RATE FEEDBACK $\{R = \sqrt{3},\ \xi = 1\}$

RECOMMENDED APPROACHES TO STEADY STATE OUT-OF-PLANE CONTROL

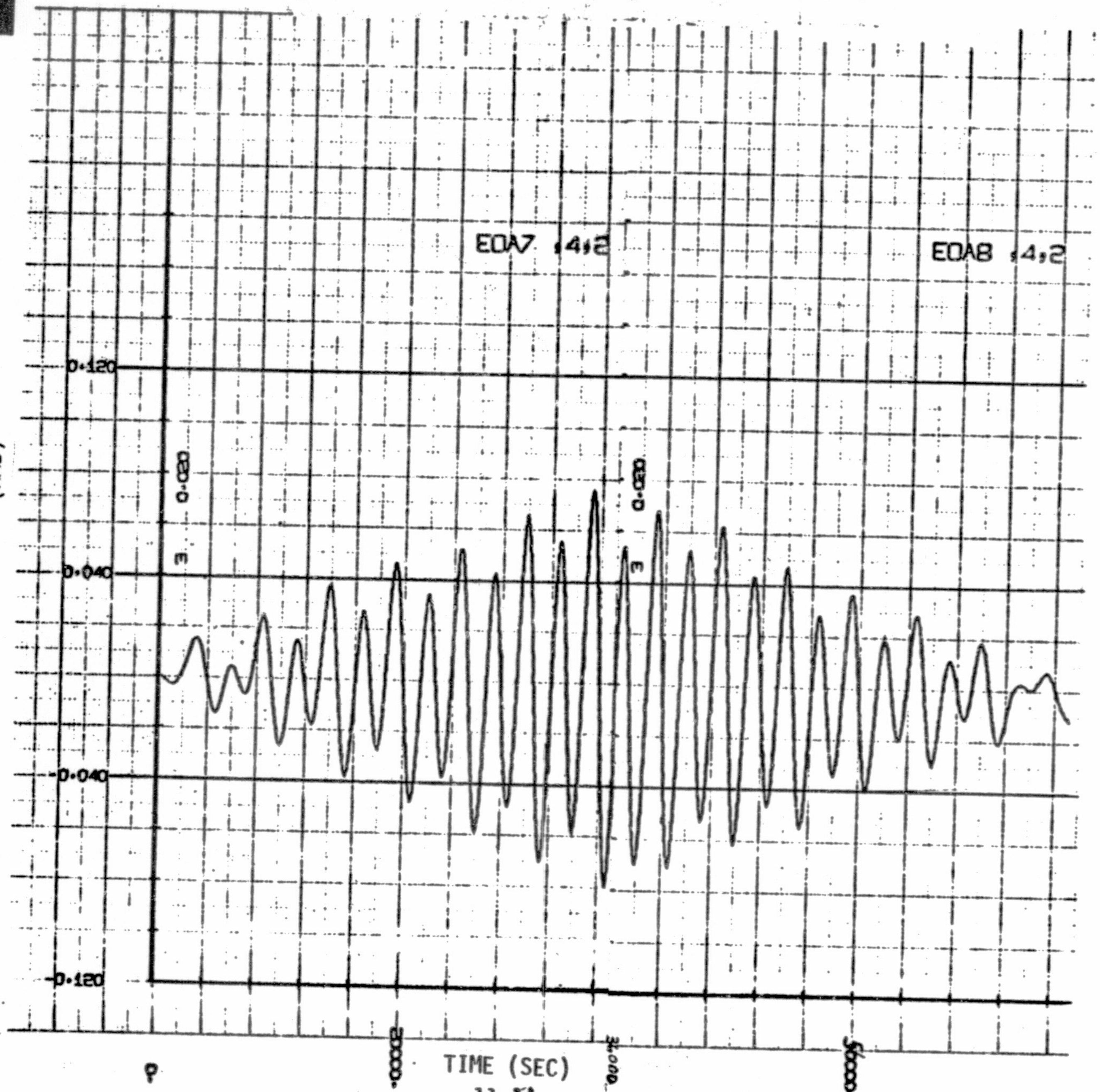
- REQUIRE ORBIT THAT AVOIDS BUILD-UP
- STATION-KEEP THE ORBITER IN-PLANE TO AVOID OR PERIODICALLY REVERSE BUILD-UP PHASE
- COMMAND LENGTH FOR CONSTANT HEIGHT (THIS WILL AVOID BUILD-UP)
- PERIODICALLY COMMAND A LENGTH SINUSOID THAT DAMPS ϕ

IMPROVED OUT-OF-PLANE DAMPING WITH MODEL FOLLOWER





PLANAR ORBITER ΔV REVERSES OUT-OF-PLANE BUILD UP
(ORBIT ECCENTRIC BY 10KM BEFORE AND AFTER ΔV)



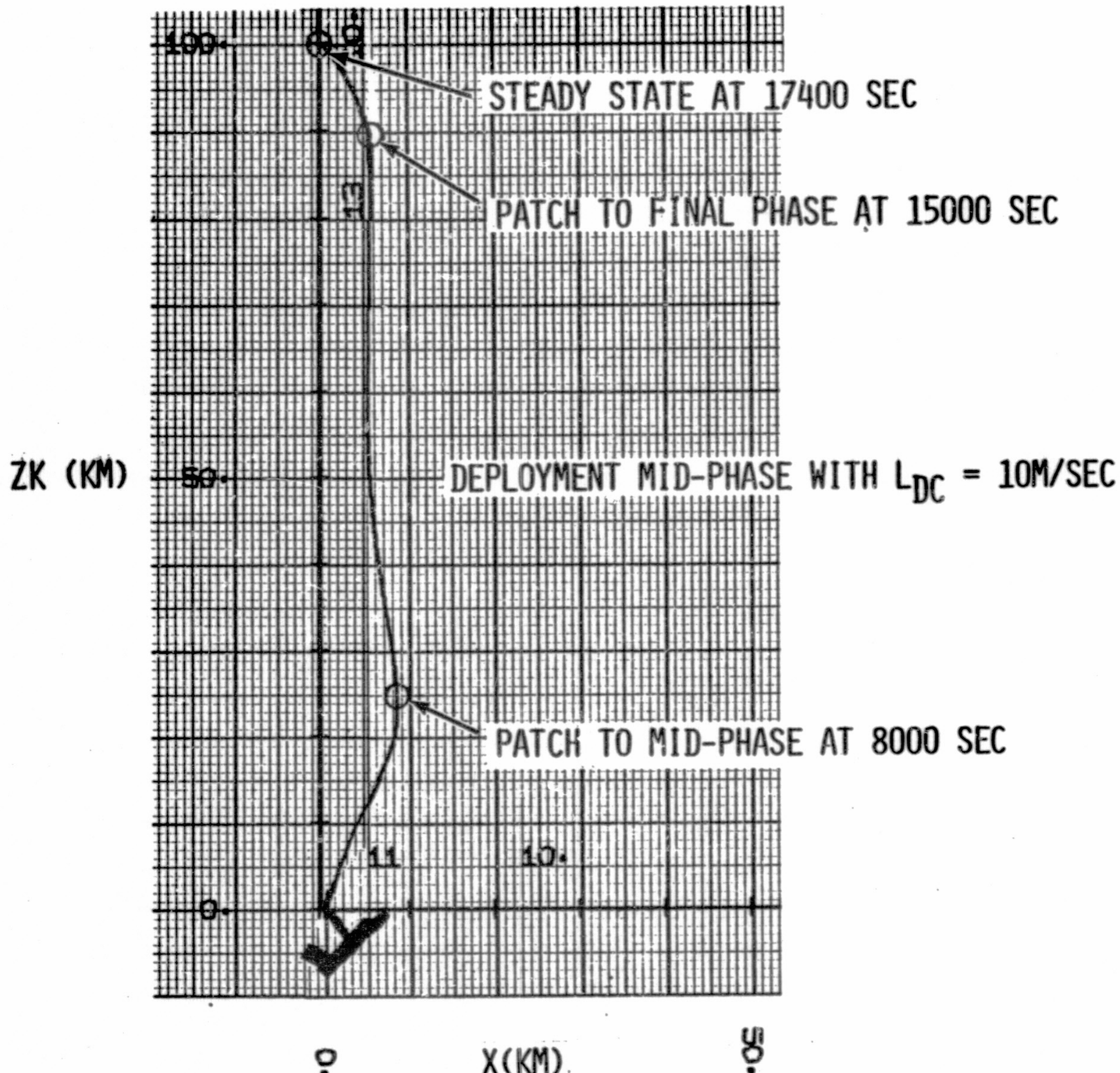
DEPLOYMENT CONTROL ACCOMPLISHMENTS

- SHOW THAT A SMALL INITIAL SPRING PUSH-OFF, AN INITIAL AFT BOOM DIRECTION, AND A COMBINED LINEAR/SINE/EXPONENTIAL COMMAND SPEED INITIAL DEPLOYMENT WITH A SMOOTH TRANSITION TO A FAST EXPONENTIAL PHASE
- SHOW THAT MID-DEPLOYMENT RATE LIMITING (PATCHING FROM AN EXPONENTIAL TO A LINEAR COMMAND) IS EASY
- SHOW THAT AN EXPONENTIAL FINAL PHASE TRANSITION TO A CONSTANT COMMAND CAN BE SMOOTHLY FOLLOWED TO EXTEND THE LAST 10 TO 20 KM IN HALF AN ORBIT
- TOTAL DEPLOYMENT TIME IS SENSITIVE TO THE INITIAL RATE, THE EXPONENTIAL TIME CONSTANT, AND TO THE RATE LIMIT. THE FASTEST SAFE DEPLOYMENT TIME IS:

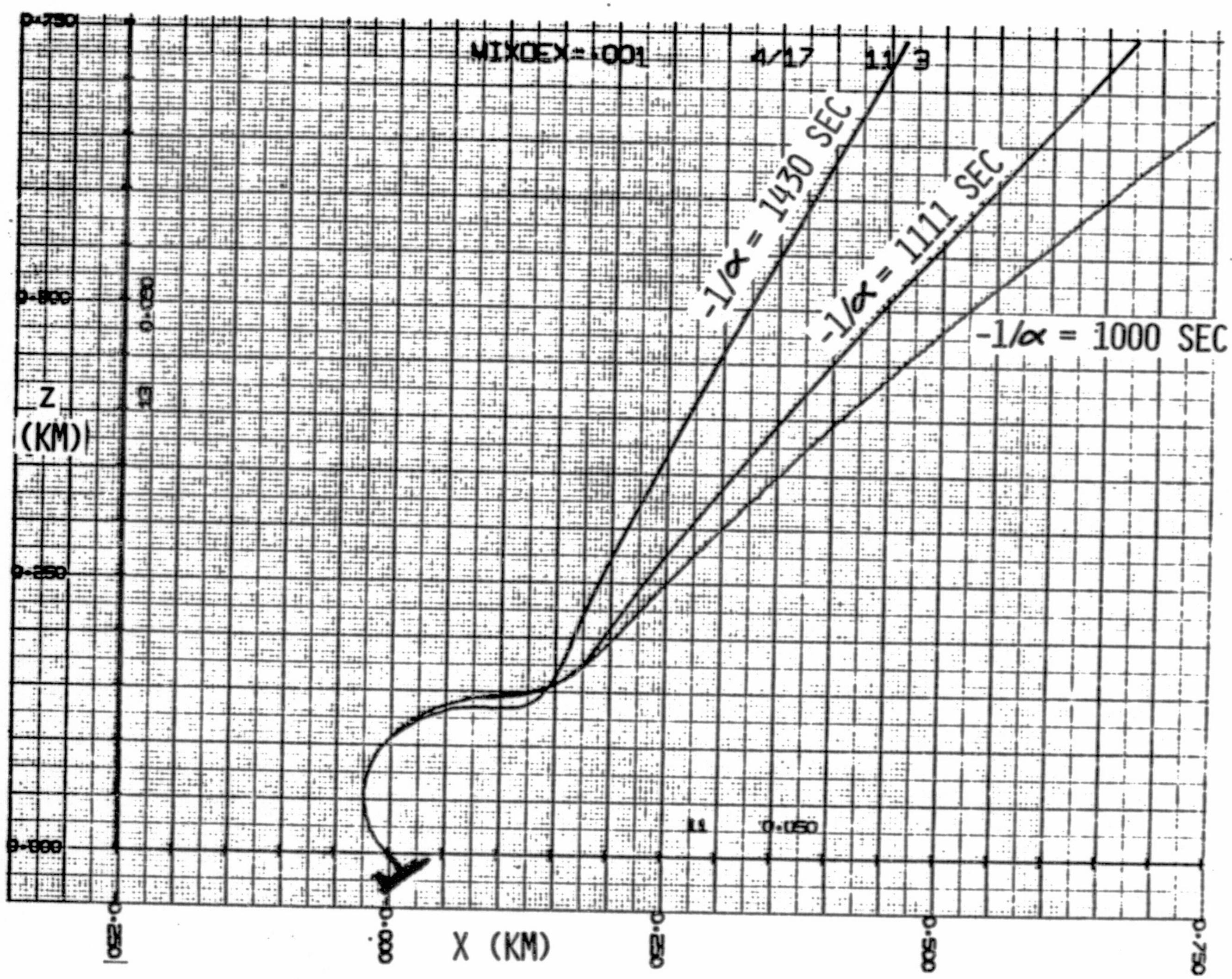
(1) $L_C(o)$ = 0.2M/SEC COMBINED WITH $-1/\alpha$ = 1400 SEC OUT TO 15 KM

(1) $\dot{L}_c$ (0) = 0.2M/SEC COMBINED WITH $-1/\alpha$ = 1400 SEC OUT TO 15KM	(8000 SEC)
(2) $\dot{L}_c$ = 10M/SEC FROM 15KM to 85KM	(7000 SEC)
(3) EXPONENTIAL FLAIR TO L_c = 100KM WITH $-1/\alpha$ = 1400 SEC	(2400 SEC)
TOTAL =	17400 SEC - 4.8 HRS

TYPICAL DEPLOYMENT IN 4.8 HOURS (SIDE VIEW)



CLOSE-UP OF FIRST DEPLOYMENT PHASE (APPROXIMATES CONSTANT TENSION INITIALLY)



RETRIEVAL CONTROL ACCOMPLISHMENTS

- DEVELOP A LARGE-ANGLE VARIABLE FREQUENCY TUNING PHILOSOPHY FOR PURE EXPONENTIAL RETRIEVAL COMMANDS AND DEMONSTRATE IMPROVED PERFORMANCE (INCLUDE FINAL POSITION AND TENSION BIAS)
- DEVELOP AN UNDERSTANDING OF RETRIEVAL SUCCESS SENSITIVITIES INCLUDING THE DETRIMENTAL EFFECT OF TETHER MASS, THE VARIABLE ADVANTAGE OF A FIXED BOOM, THE ADVANTAGE OR OUT-OF-PLANE ORBITER ΔV'S, AND THE ADVANTAGE OF BOOM POINTING DURING FINAL PULL IN.
- DEVELOP A SUPERIOR RETRIEVAL COMMAND APPROACH WHICH STARTS WITH A LINEARLY DECREASING LENGTH (FOR A RATE LIMIT OF 10M/SEC IT TAKES 7500 SEC TO RETRIEVE TO 25 KM)
- A PURE EXPONENTIAL CAN BE USED ALL THE WAY TO 1 METER BUT THE EXPONENTIAL TIME CONSTANT MUST BE AT LEAST 4444 SEC TO ALLOW NON-LINEAR STRETCH COUPLING ALONE TO DAMP OUT-OF-PLANE ERRORS AS LARGE AS 5 KM. TOTAL RETRIEVAL TIME IS 13 HOURS.
- OUT-OF-PLANE ORBITER ΔV'S REDUCE TOTAL RETRIEVAL TIME TO 1 METER TO 8 HOURS. THIS PERMITS USING A 2500 SEC EXPONENTIAL WHICH SAFELY CONTROLS PLANAR LIBRATION THROUGH STRETCHING ALONE.

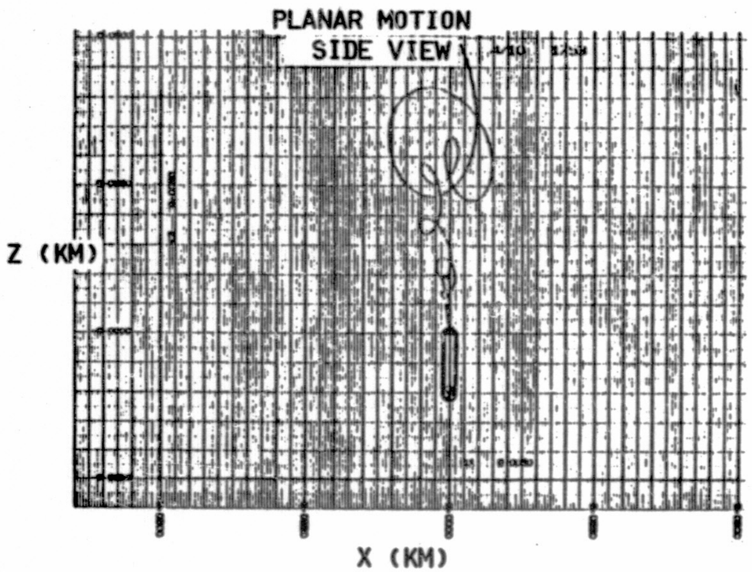
  (FOR AN INITIAL OUT-OF-PLANE ERROR OF 5KM)

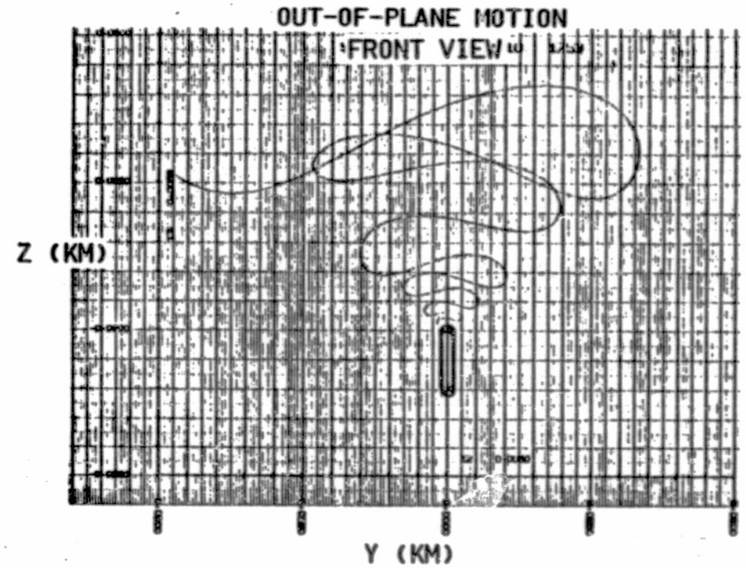
  ($\Delta V_1 \simeq 10$ M/SEC, $L_1 \simeq 25$KM, $T_1 \simeq 7500$ SEC)

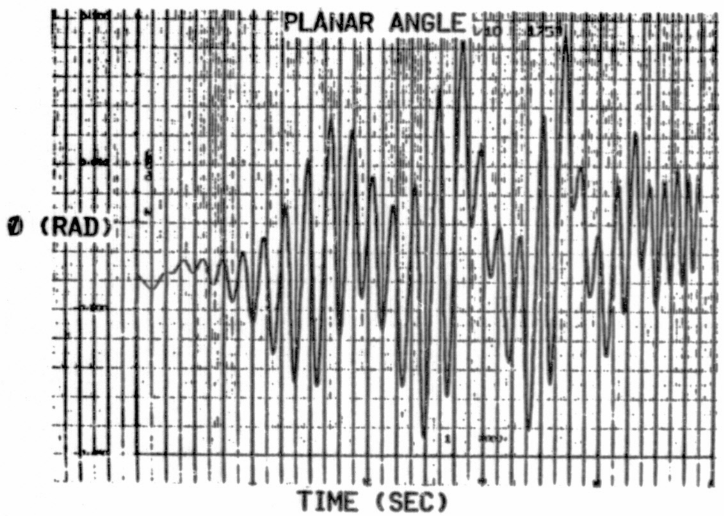
  ($\Delta V_2 \simeq 1$ M/SEC, $L_2 \simeq 1$KM, $T_2 \simeq 15000$ SEC)

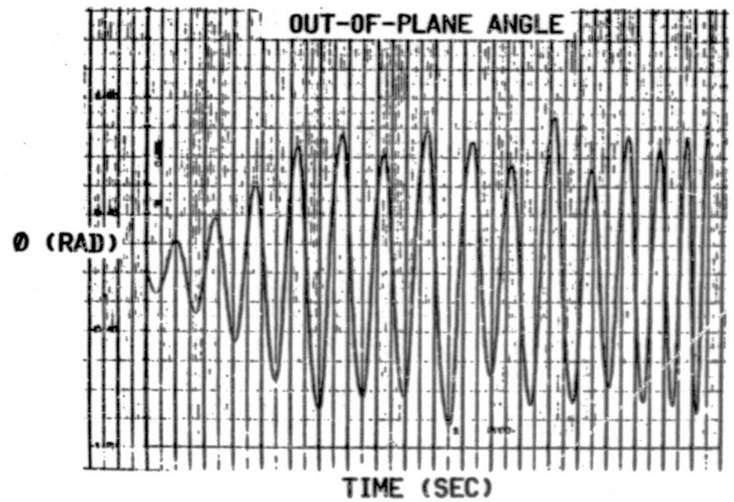
  ($\Delta V_3 \simeq 0.1$ M/SEC, $L_3 \simeq 50$M, $T_3 \simeq 21000$ SEC)
- THE SATELLITE CAN BE PULLED IN THE LAST 40 TO 80 METERS AT A CONSTANT RATE OF ABOUT 0.1 M/SEC IF THE ORBITER POINTS THE BOOM AT THE SATELLITE. THIS ALLOWS A TOTAL RETRIEVAL TIME AS SHORT AS (6 HOURS). (WE HAVE ONLY SIMULATED PLANAR POINTING TO DATE).

COUPLING BETWEEN PLANAR AND OUT-OF-PLANE MOTIONS LIMITS PURE EXPONENTIAL RETRIEVAL TIME

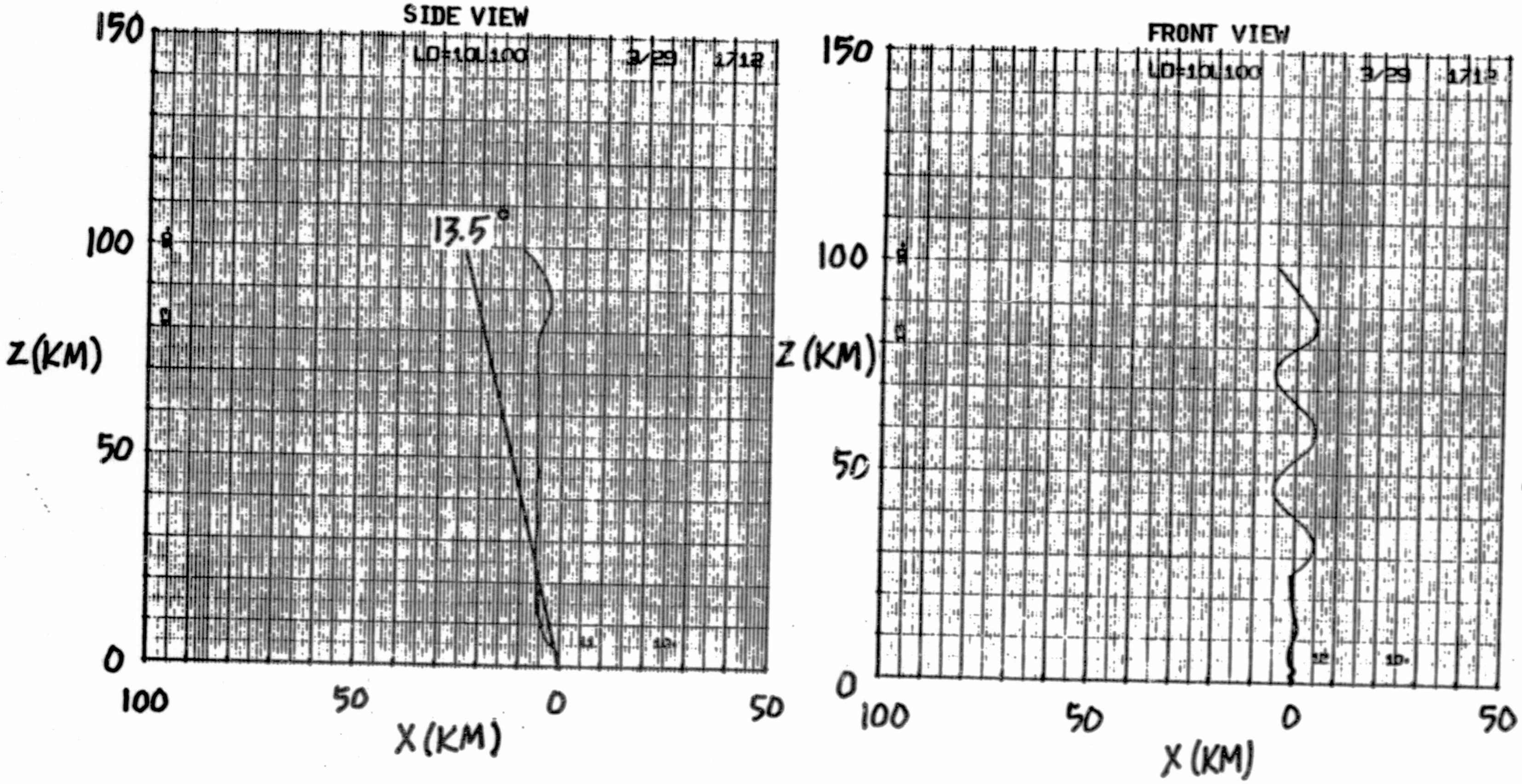






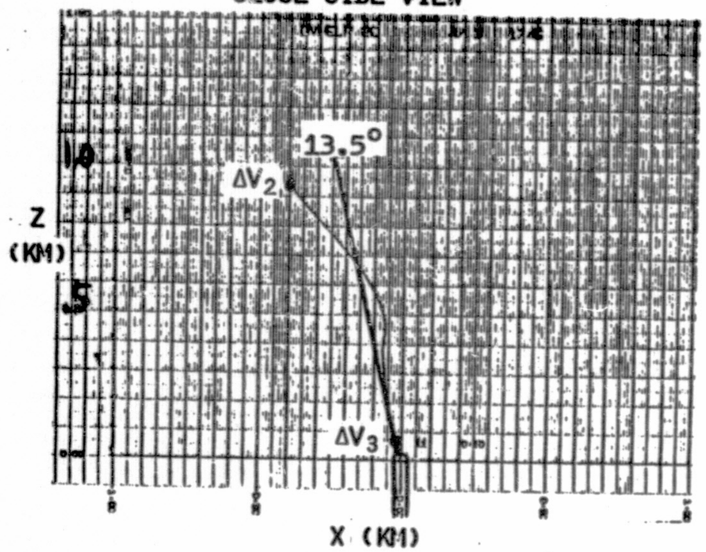


OVERVIEW OF OUT-OF-PLANE ΔV ASSISTED RETRIEVAL

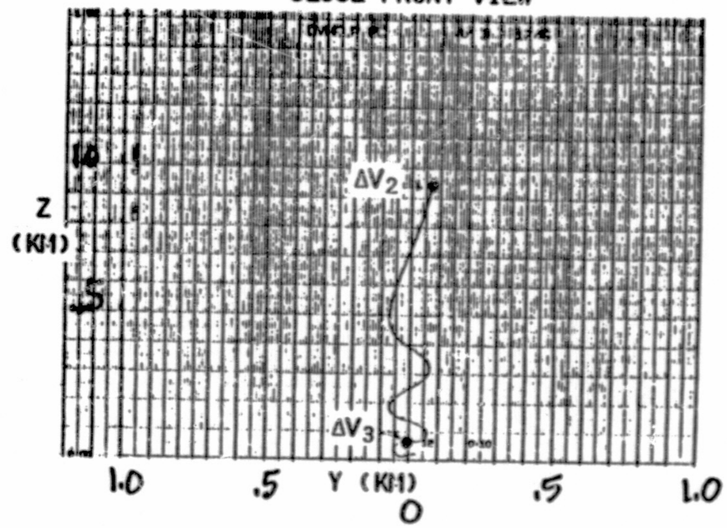


CLOSE-UP OF OUT-OF-PLANE ΔV ASSISTED RETRIEVAL

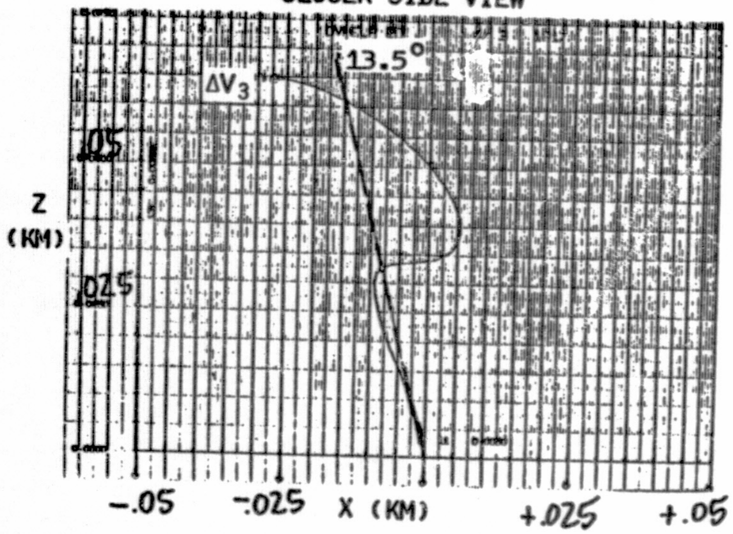
CLOSE SIDE VIEW



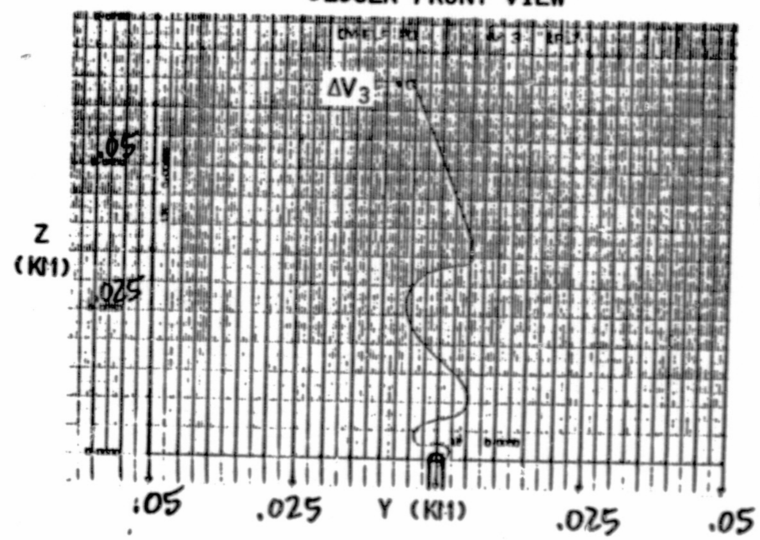
CLOSE FRONT VIEW



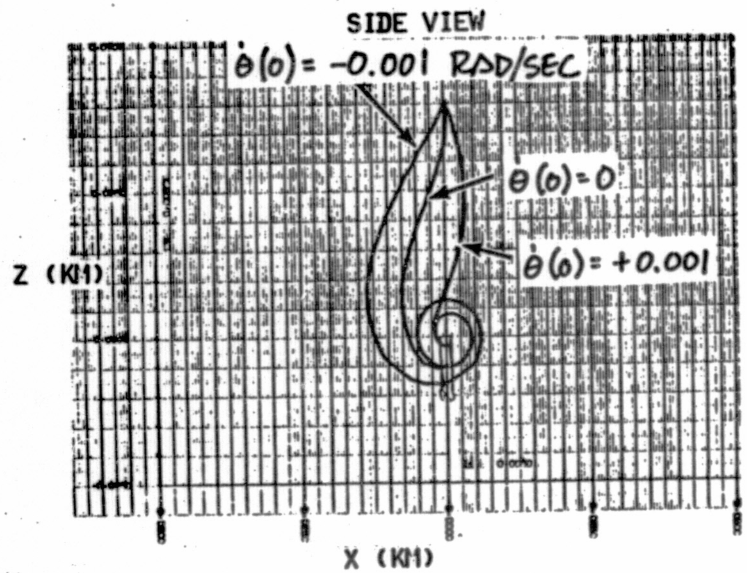
CLOSER SIDE VIEW

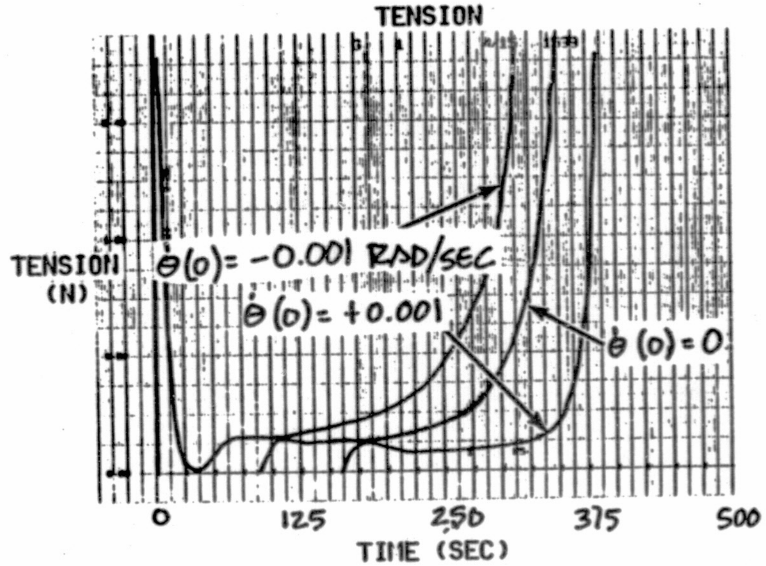


CLOSER FRONT VIEW



WITH A CONSTANT BOOM ATTITUDE, A 0.1 M/SEC FINAL PULL-IN CAUSES VERY HIGH TENSION AND WRAP-UP





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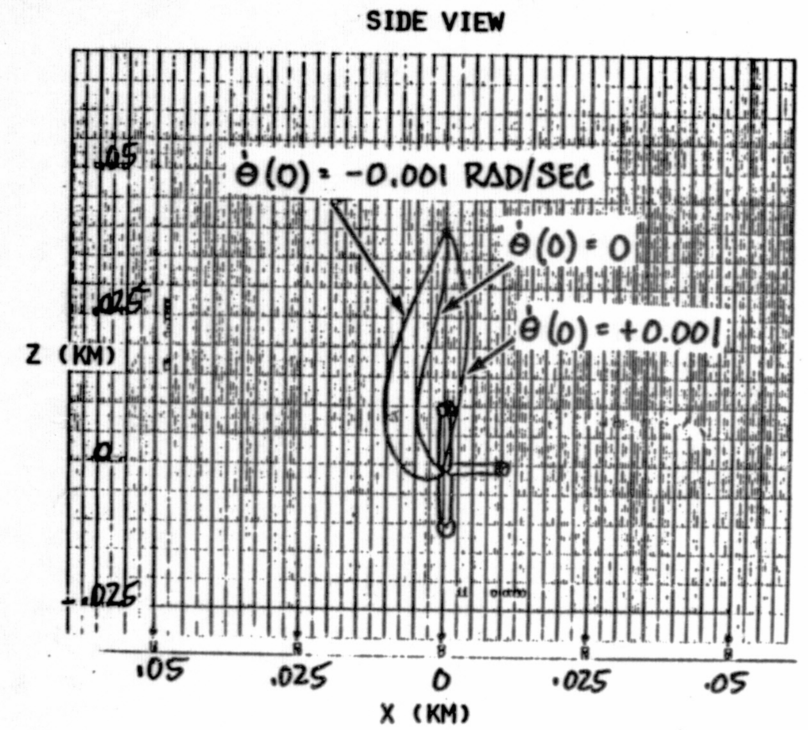
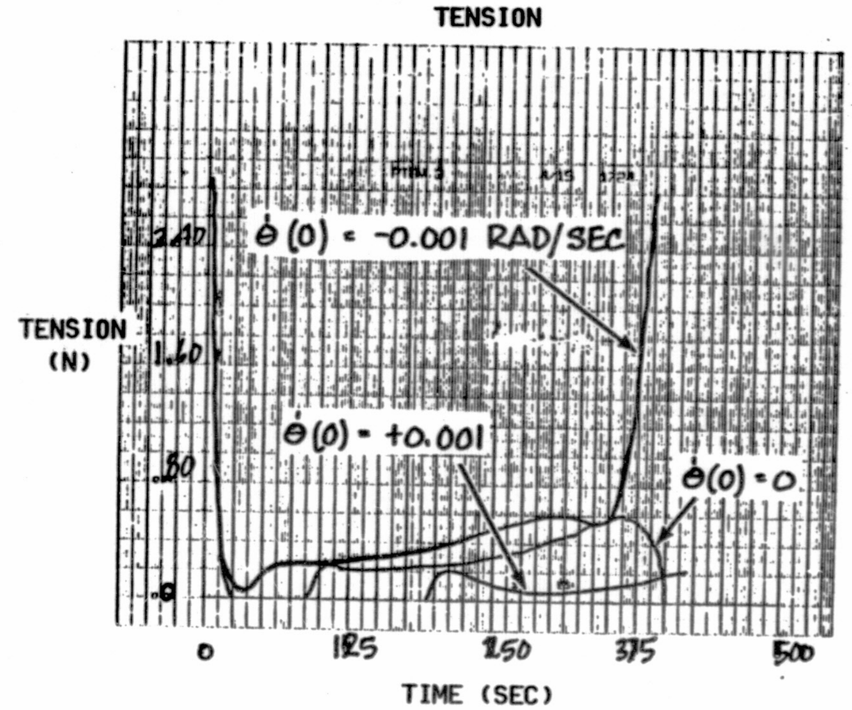
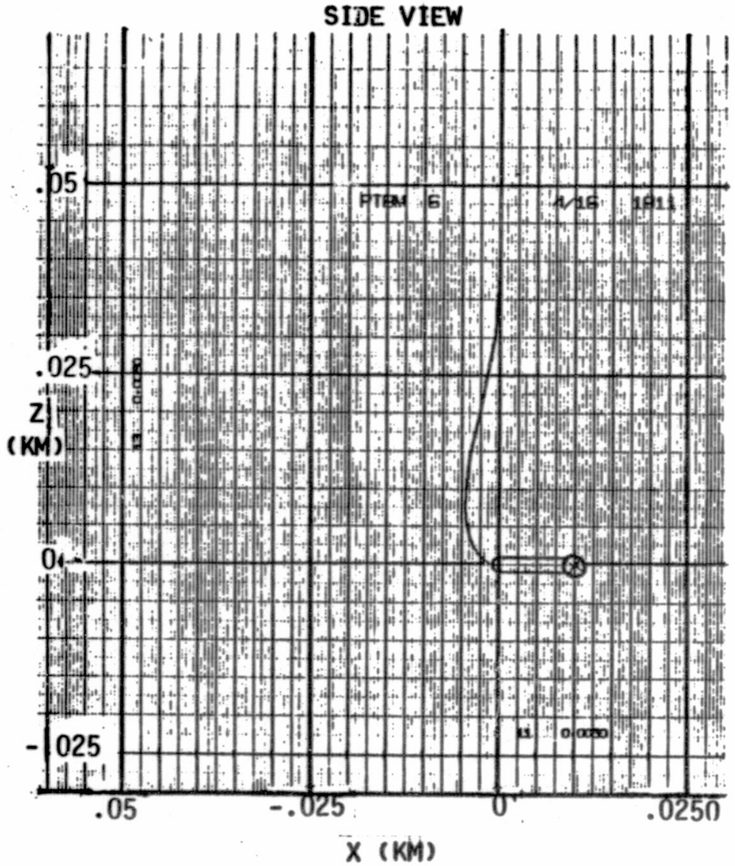
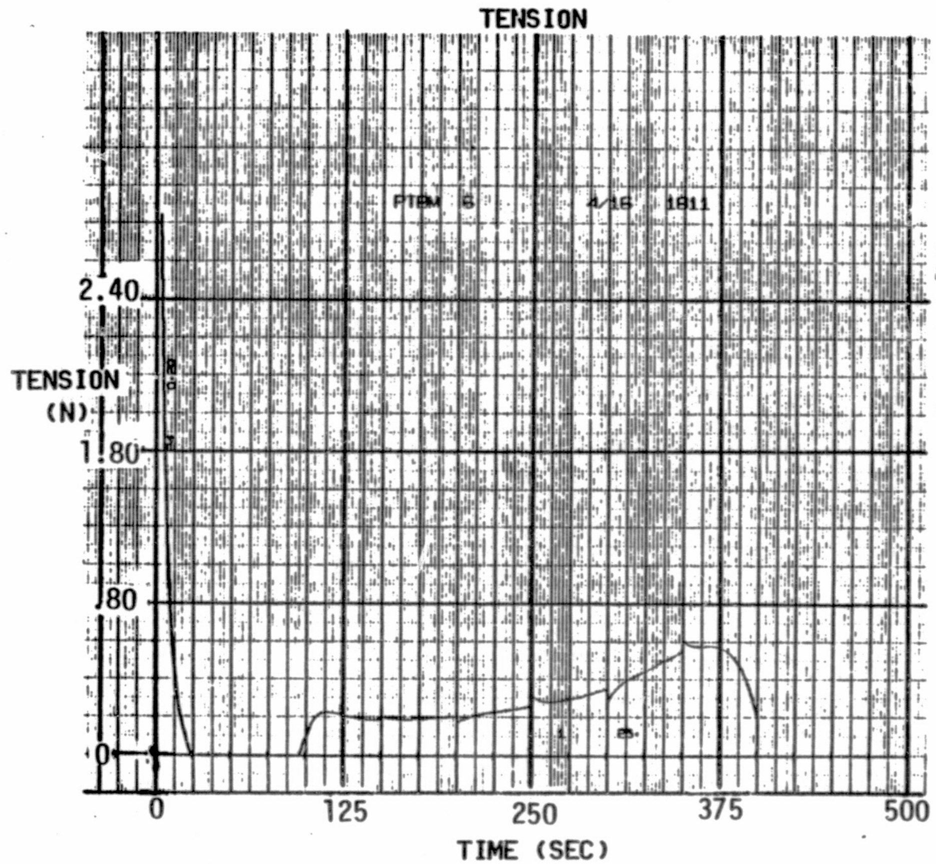
POINTING THE BOOM PERMITS SUCCESSFUL DOCKING (FINAL TENSION IS SENSITIVE TO INITIAL LIBRATION RATE)



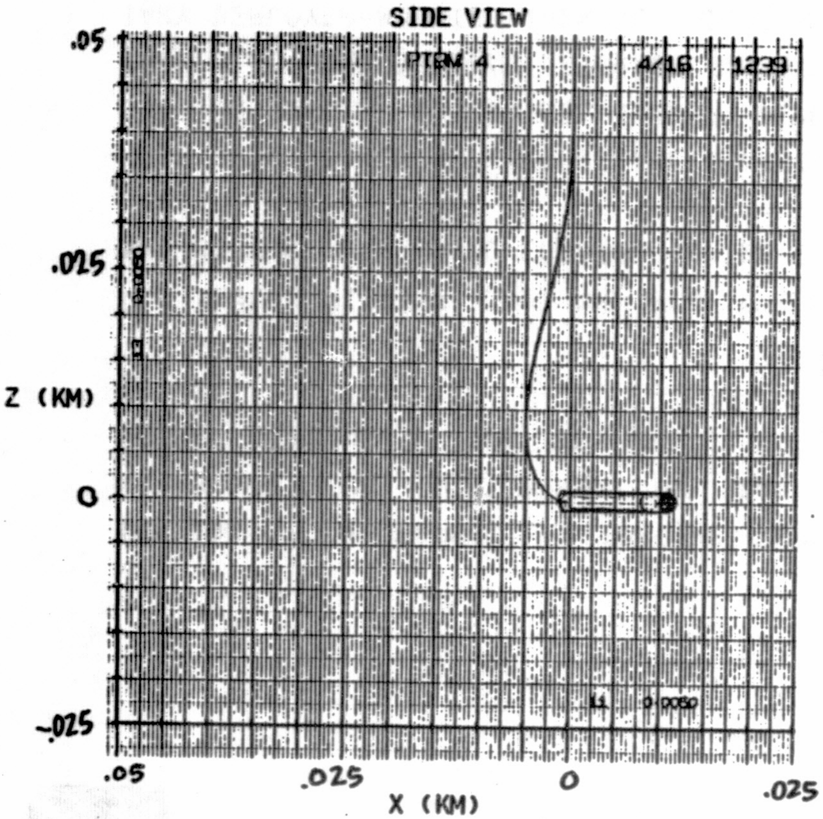


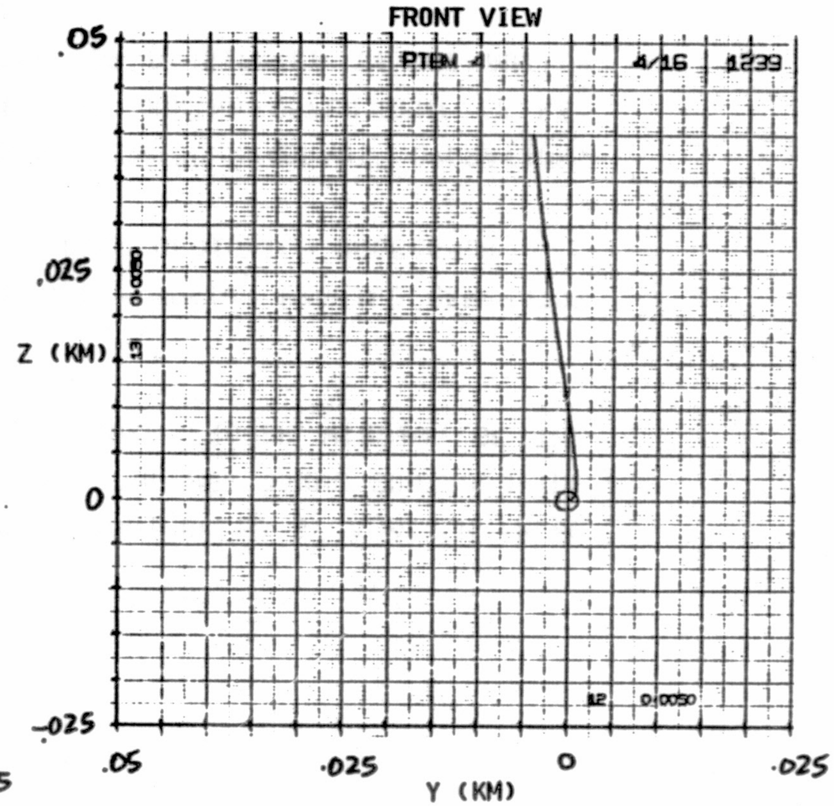
REASONABLE BOOM POINTING ERRORS ARE TOLERABLE (0.6 DEG ORBITER LIMIT CYCLE WITH 50 SEC PERIOD)





SMALL OUT-OF-PLANE ERRORS DON'T CAUSE TROUBLE EVEN WHEN THE BOOM POINTS ONLY IN PITCH



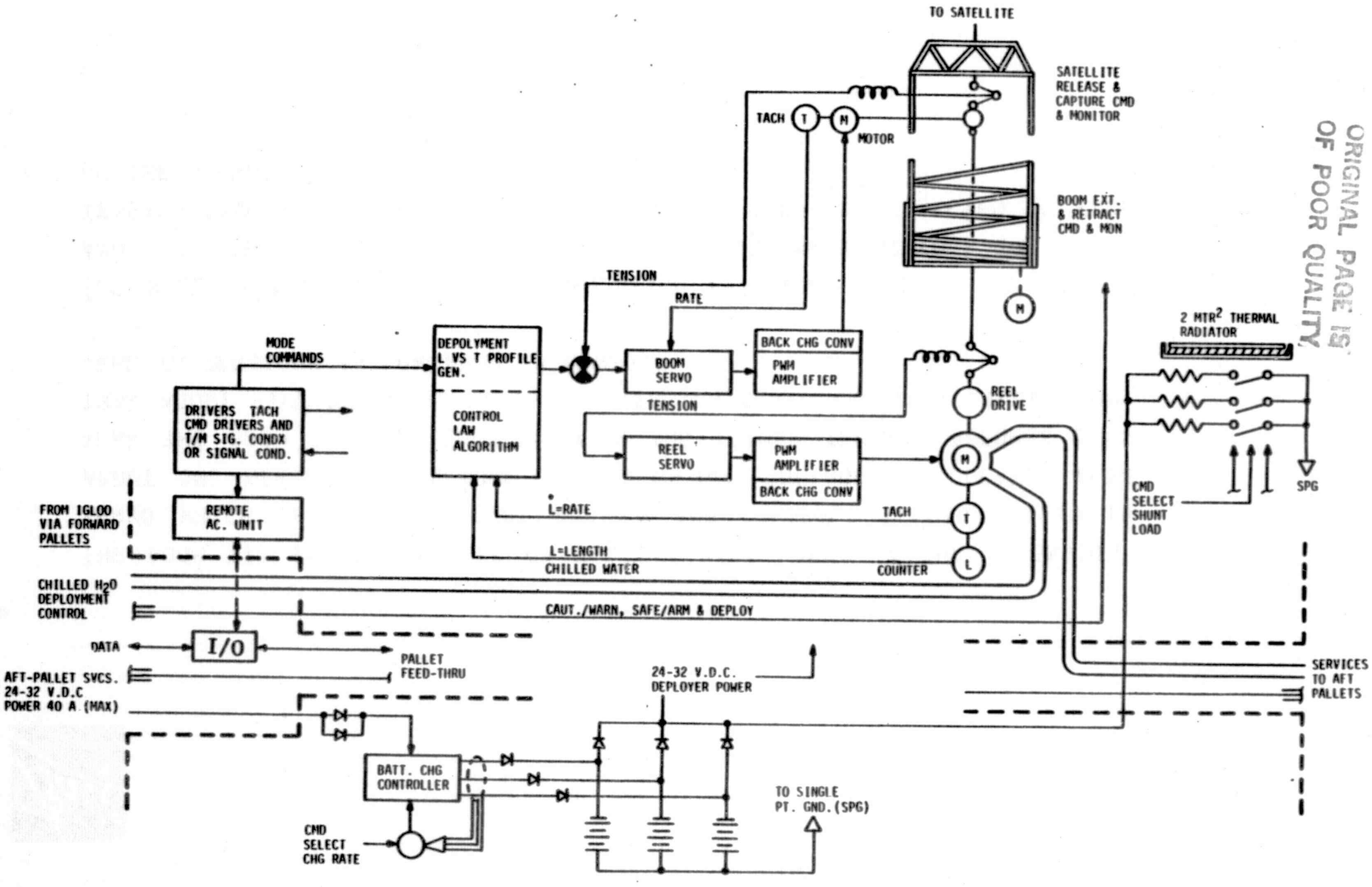


TENSION OF THE TETHER LEAVING THE BOOM IS CONTROLLED BY A PINCH WHEEL AND SERVO DRIVE LOCATED NEAR THE BOOM TIP. ANOTHER SERVO CONTROLS THE TETHER TENSION AT THE STORAGE DRUM TO ENSURE PROPER WINDING OF THE TETHER.

THE SERVOS RECEIVE COMMANDS FROM THE LENGTH-TENSION PROFILE GENERATOR AND CONTROL LAW LOGIC LOCATED IN THE DEPLOYER DEDICATED PROCESSOR.

BOTH SERVO POWER AMPLIFIERS ARE CONFIGURED FOR "4-QUADRANT" OPERATION, SO THAT EXCESS ELECTRICAL ENERGY DEVELOPED DURING DEPLOYMENT IS RETURNED TO THE DEPLOYER STORAGE BATTERIES OR DISSIPATED IN THE AUXILIARY DEPLOYER-MOUNTED THERMAL RADIATOR.

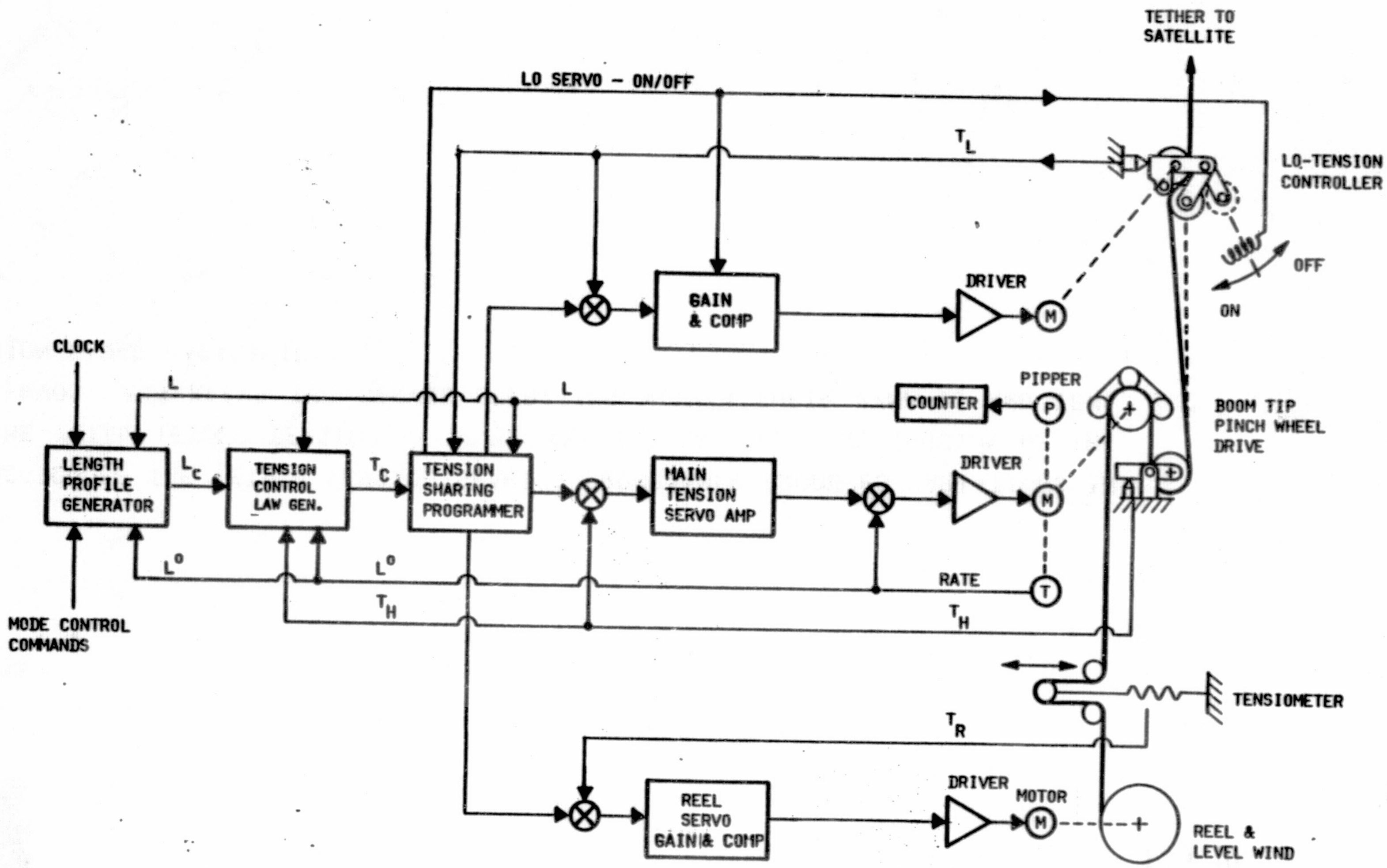
TETHERED SATELLITE PALLET-MOUNTED DEPLOYER



THE BOOM TIP SERVO CONSISTS OF TWO FEEDBACK LOOPS, A "MAIN TENSION" SERVO WHICH IS OPERATED CONTINUOUSLY AND CONTROLS TENSIONS DOWN TO ABOUT ONE NEWTON. A SECOND "LOW TENSION" CONTROLLER, LOCATED ALSO NEAR THE BOOM TIP, IS ENGAGED WHEN THE TETHER TENSION BECOMES LESS THAN ABOUT FIVE NEWTONS. THIS LOW TENSION SERVO PROVIDES LINEAR CONTROL TO TENSIONS AS LOW AS 0.15 NEWTONS.

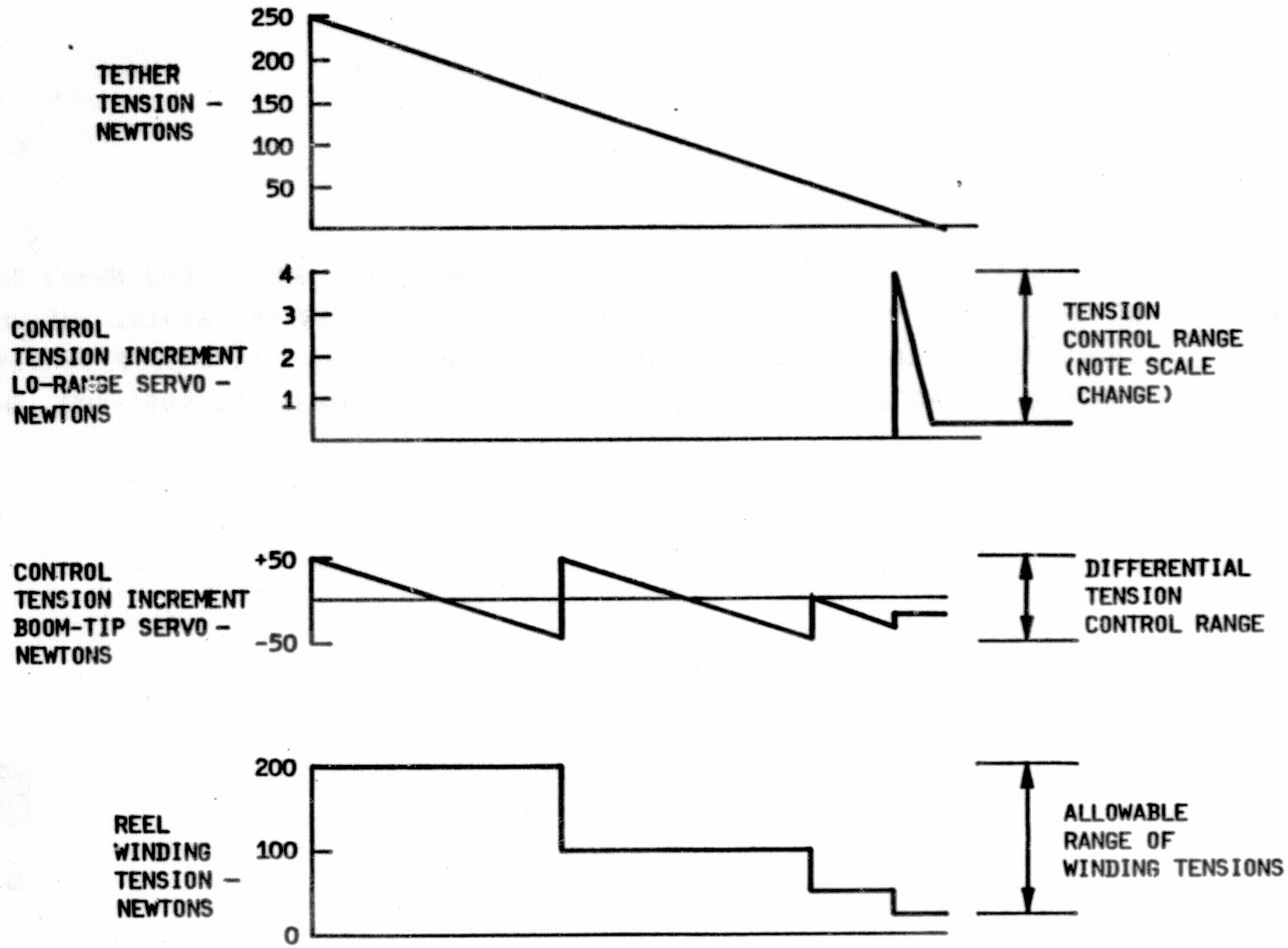
THE REEL TENSIOMETER PROVIDES ISOLATION BETWEEN THE BOOM TIP SERVOS AND THE REEL SERVO. A TENSION SHARING PROGRAMMER DIVIDES THE TOTAL TENSION REQUIRED INTO DIFFERENTIAL TENSION COMMANDS DIRECTED TO EACH OF THE SERVOS.

DEPLOYER-TETHER CONTROL SERVO SYSTEM



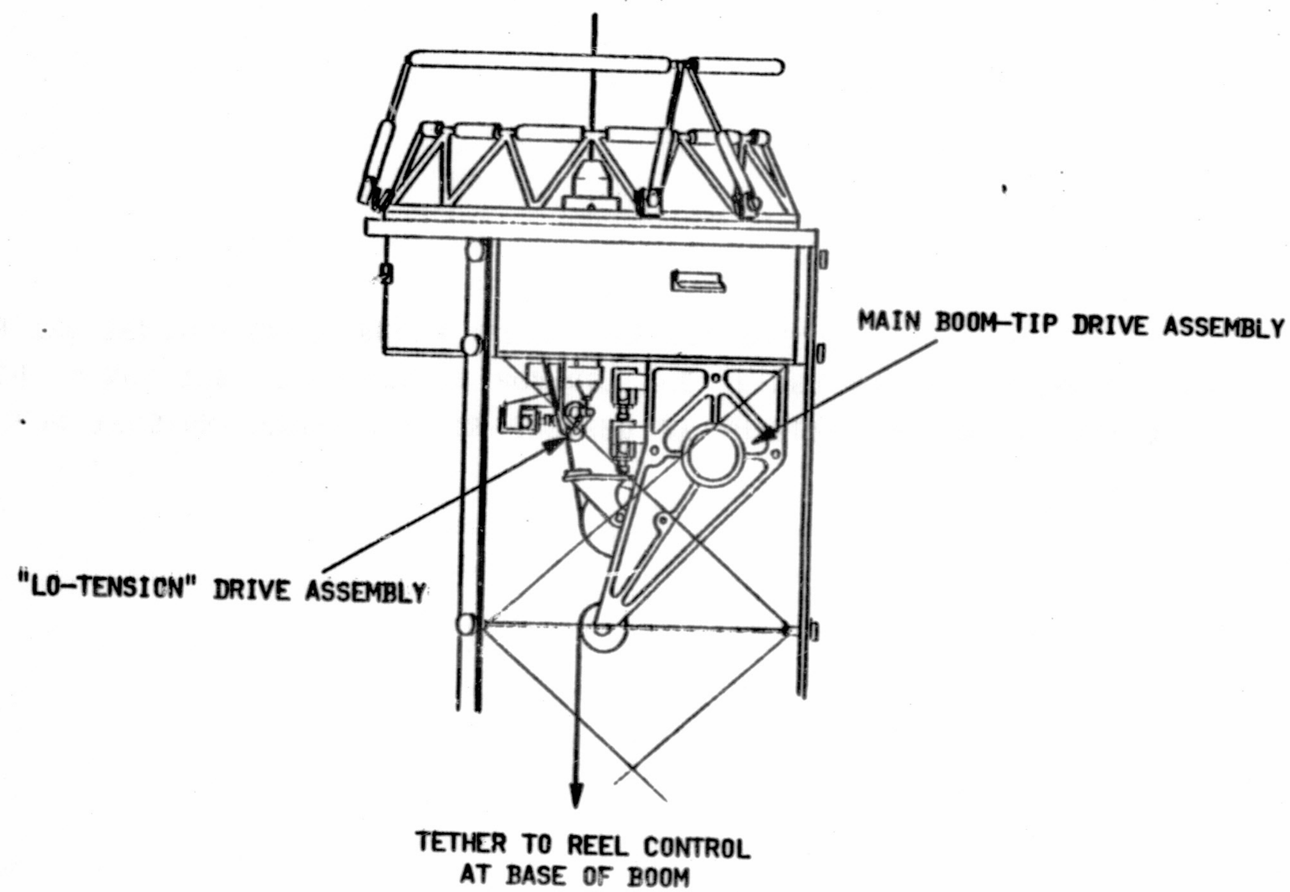
ACTION OF THE TETHER TENSION SHARING PROGRAMMER PRODUCES VARIATIONS IN THE TOTAL TETHER TENSION BY ADJUSTING THE DIFFERENTIAL TENSION OF THE SERVOS, AND KEEPS THE SERVOS OPERATING WITHIN THEIR DYNAMIC AND TENSION RANGE CAPABILITIES.

TENSION SHARING–DEPLOYER SERVOS 500 KG SATELLITE – 150 KG TETHER



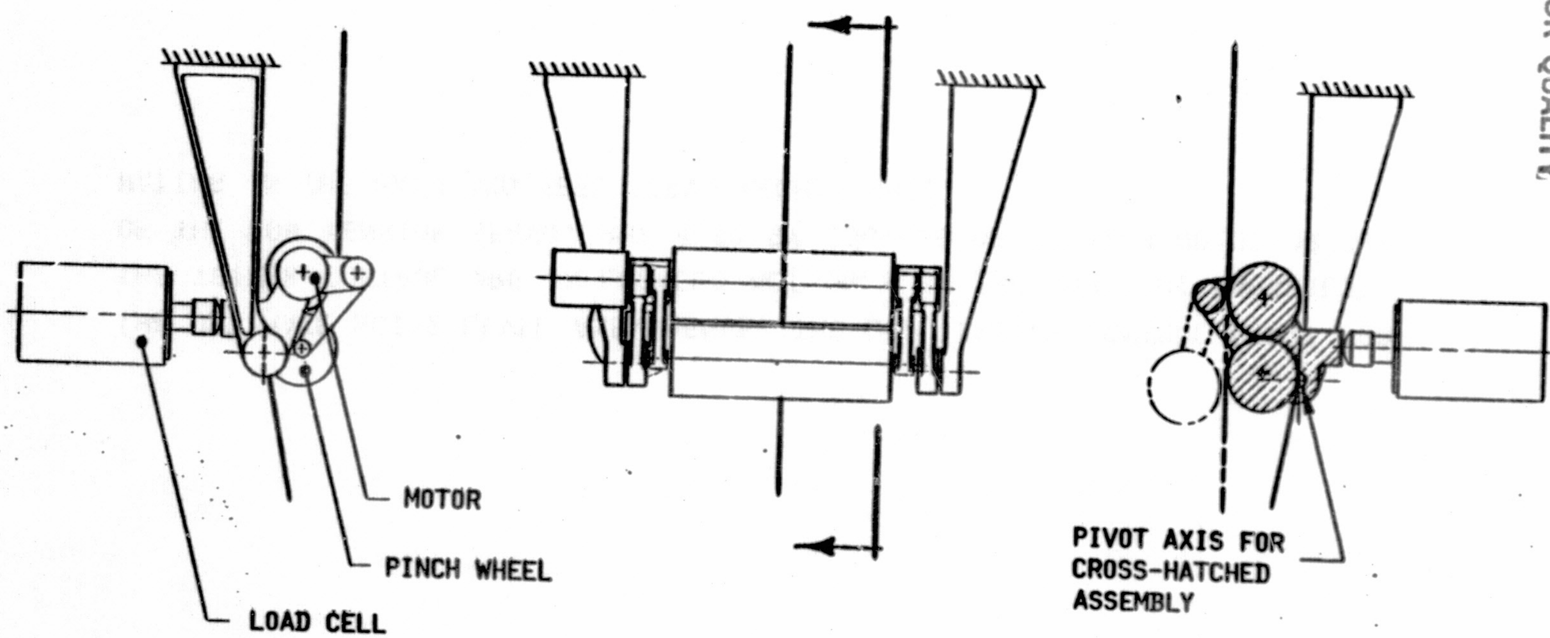
THE "LOW TENSION" SERVO DRIVE IS LOCATED IMMEDIATELY BELOW THE DROGUE-CAPTURE ASSEMBLY. THE SERVO REMAINS DISENGAGED FOR HIGHER TENSIONS AND THE TETHER PASSES DIRECTLY FROM THE MAIN SERVO INTO THE EYELET ON THE LOWER END OF THE DROGUE PROBE.

BOOM-TIP TETHER CONTROLLERS



THE LOW TENSION CONTROLLER IS ENGAGED BY AN ELECTROMAGNETIC ACTUATOR WHICH SWINGS THE PINCH ROLLER AGAINST THE TETHER AND AN IDLING ROLLER WHEN THE TENSION FALLS BELOW ABOUT FIVE NEWTONS.

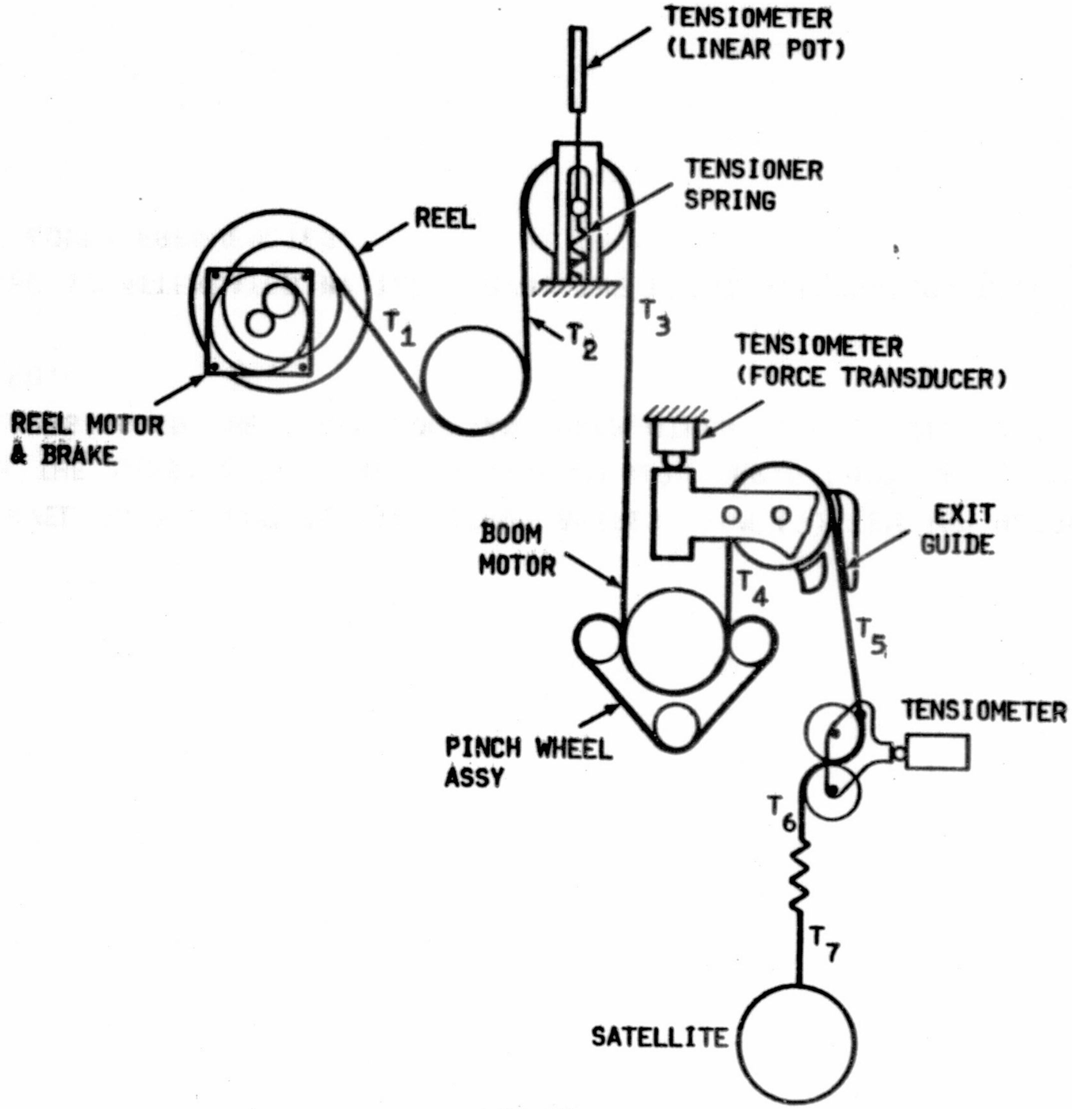
"LO-TENSION" TETHER CONTROLLER



THE ULTIMATE NOISE LEVEL AND, HENCE, THE LOW TENSION CONTROL LIMIT FOR THE TETHER CONTROL ARE INFLUENCED NOT ONLY BY THE INHERENT CAPABILITY OF THE LOW TENSION SERVO, BUT ALSO BY SOURCES OF TENSION NOISE ORIGINATING IN THE MAIN AND REEL SERVO MECHANISMS.

Ball

SERVOS-COUPLED BY TETHER TENSION



THE NOISE LEVEL IN THE LOW TENSION SERVO ARISES FROM (1) TENSION NOISE INHERENT IN THE SENSING LOOP OF THE LOW TENSION SERVO LOOP, (2) TENSION NOISE ARISING IN THE SERVO LOOP AND FROM OTHER SOURCES WITH WHICH IT IS COUPLED.

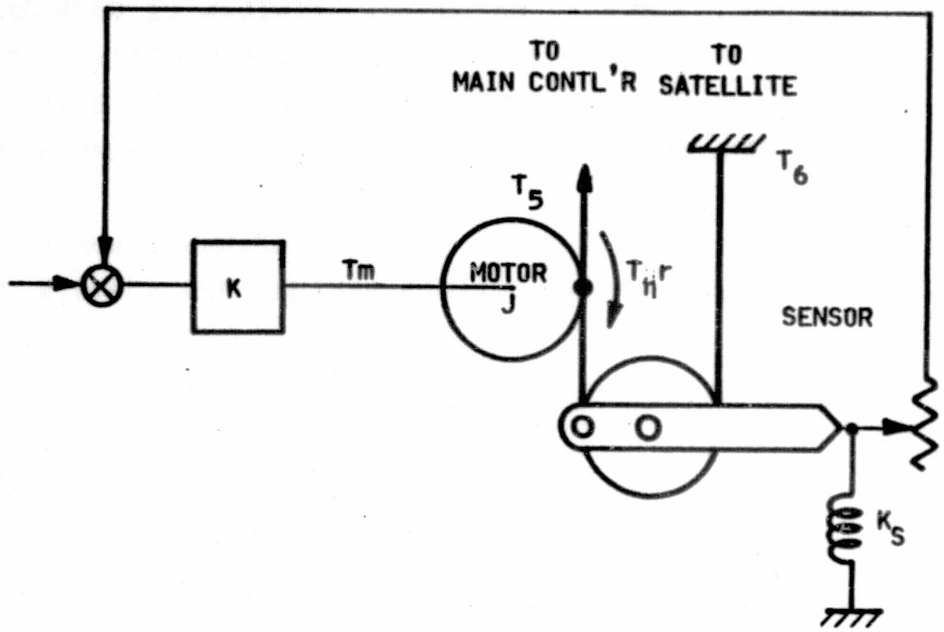
TENSION NOISE IS ATTENUATED BY THE SERVO, THE LEAST ATTENUATION OCCURRING AT THE LOWER FREQUENCIES.

BOOM- TIP LO-TENSION SERVO RESPONSE

$$T_G = 0.15\ T_{1B(5-6)} + T_{S3}$$

NOISE LEVEL = (SERVO ATTENUATION) (TENSION NOISE) + SENSOR NOISE

$$= 0.15\ (24.5 \times 10^{-2}) + 0.8 \times 10^{-2} = 4.5 \times 10^{-2} \text{ NEWTONS}$$



$$\frac{T_6}{T_\eta} = \frac{K_T r/J}{\frac{s^2+K+K_T r}{J}}$$

$$\frac{T_7}{T_\eta} = \frac{1}{\frac{K}{K_T} r + 1} = \frac{K_T r/J}{\beta^2}$$

$= 0.15$

$=$ SERVO ATTENUATION

NOISE SIGNALS ARE FURTHER LIMITED BY THE FREQUENCY RESPONSE OF THE LOW TENSION SERVO SYSTEM.

SIGNALS AT FREQUENCIES LOWER THAN ABOUT ONE HERTZ ARE ESSENTIALLY ELIMINATED BY THE INTEGRAL FEEDBACK IN THE SERVO LOOP. SIGNAL COMPONENTS AT FREQUENCIES GREATER THAN ABOUT 12 TO 15 HERTZ ARE ELIMINATED BY THE NEED TO MINIMIZE THE SERVO RESPONSE TO MECHANICAL RESONANCES IN THE SERVO DRIVE MECHANISM.

NOISE SOURCES & INPUTS TO LO-TENSION SERVO

TENSION NOISE	WIDEBAND TOTAL	IN-BAND FREQUENCY > 1 HZ
t_{fB} = BEARING FRICTION	0.02 N	0.001 N (5%)
t_{fP} = PITCH WHEEL FRICTION	0.4	0.06 (15%)
t_{fM} = MOTOR FRICTION	0.12	0.024 (20%)
t_{5N} = NOISE FROM MAIN TIP SERVO	1.6	0.16 (10%)
$T_{1B\ (5-6)}$ = TOTAL IN-BAND TENSION	NOISE = 24.5×10^{-2} N	

SENSOR NOISE - TS3	
t_{PBN} - PIVOT BEARING	0.0018 N
t_{xDCR} - TRANSDUCER REPEATABILITY	0.006
T_{S3} - TOTAL SENSOR NOISE	0.78×10^{-2} N

LOW TENSION NOISE DUE TO LOSSES IS ESSENTIALLY A FUNCTION OF THE FRICTIONAL LOSSES AND HYSTERESIS OF THE INDIVIDUAL HARDWARE COMPONENTS.

DERIVATION OF TOTAL FRICTION - LO TENSION SERVO

t_{Bf} = BEARING FRICTION

$$= \mu_b \frac{D_b}{D_p} n = 0.018 \text{ N}$$

WHERE: $\mu_b = 0.0015$ ①

F_N = NORMAL FORCE = T/μ_s

T = SLIP TENSION = 6 N

μ_s = STATIC FRICTION = 0.3

D_b = BEARING DIA. = 0.5"

D_p = PULLEY DIA. = 2"

n = No. SHAFTS = 2.4 ③

t_{Pf} = TETHER PINCH FRICTION

$$= \mu_r F_N = 0.4 \text{ N}$$

WHERE: μ_r ② = ROLLING COEF. = 0.02

$F_N = T/\mu_s$

t_{Mf} = MOTOR FRICTION

$$= \mu_m T = 0.12 \text{ N}$$

WHERE: μ_m = MOTOR LOSSES = 0.02

t_{5N} = NOISE FROM MAIN TIP SERVO

= 1.6 N

$$\boxed{T_{5-6N} = T_{Bf} + t_{Pf} + t_{mf} + t_{5N} = 1.6 \text{ N}}$$

NOTES:
① MARKS HANDBOOK PG. 8-140
② MARKS HANDBOOK PG. 3-28
③ 2 MAIN SHAFTS PLUS MOTOR SHAFT

IN TURN, THE NOISE CONTRIBUTION FROM THE MAIN SERVO IS DETERMINED BY THE FRICTIONAL LOSSES AND HYSTERESIS PRESENT IN THE MAIN BOOM TIP SERVO.

DERIVATION OF NOISE FROM MAIN BOOM TIP SERVO

t_{m2} = MOTOR FRICTION

$= T\mu_m = 0.75\ N$

WHERE: μ = MOTOR LOSSES = 0.015

$T = 50\ N$

t_{p2} = TETHER PINCH FRICTION

$= \mu_r \frac{T}{\mu_s} \approx 5\ N$

WITH μ_r = RUNNING FRICT. = 0.03

μ_s = STATIC FRICT. = 0.3

t_{s2} = SENSOR NOISE

$= \mu_b \frac{D_b}{D_p} \frac{T}{\mu_s} \eta + TS$

= PIVOT FRICT + REPEATABILITY

$= 0.00015 \frac{1.5}{2} \frac{200}{0.3} 1 + (200)(0.0007) = 0.52\ N$

t_{3N} = REEL SERVO NOISE

WITH T = 200 N, SERVO GAON = 10

$\mu_m = 0.015, \mu_{GB} = 0.1,$

μ SENSOR $= 0.05 \times \frac{200}{4} = 2.5$

$$t_{3N} = \frac{T(\mu_m + \mu_{GB})}{10} + \mu_{SENSOR} = 4.8\ N$$

$$\boxed{T_{5N} = \frac{0.75 + 5 + 4.8}{10} + 0.52 = 1.6\ N}$$

SENSOR NOISE IN THE LOW TENSION SERVO ARISES FROM THE INHERENT MEASUREMENT CAPABILITY OF THE TENSION SENSOR AND FROM THE ASSOCIATED SENSOR PIVOT FRICTION CHARACTERISTICS.

SENSOR NOISE OF LO-TENSION BOOM TIP SERVO

t_{PBN} = PIVOT BEARING FRICTION

$= 0.18 \times 10^{-2}$ N

WITH: $T = 6$ N, $D_b = 0.4"$, $D_p = 2$

t_{XDCR} = REPEATABILITY OF SENSOR

$= T \times \delta = 6 \times 0.0007 = 0.42 \times 10^{-2}$ N

WHERE δ IS DEVICE REPEATABILITY AS FRACTION OF LEVEL.

$\boxed{T_{S3} = \text{TOTAL SENSOR NOISE} = 0.6 \times 10^{-2} \text{ N.}}$

SERVO NOISE STUDY – CONCLUSIONS

- EXPECTED NOISE LEVEL ON TETHER TENSION WILL NOT EXCEED 0.05 NEWTONS
- MINIMUM CONTROLLABLE TENSION SHOULD NOT EXCEED 0.15 NEWTONS

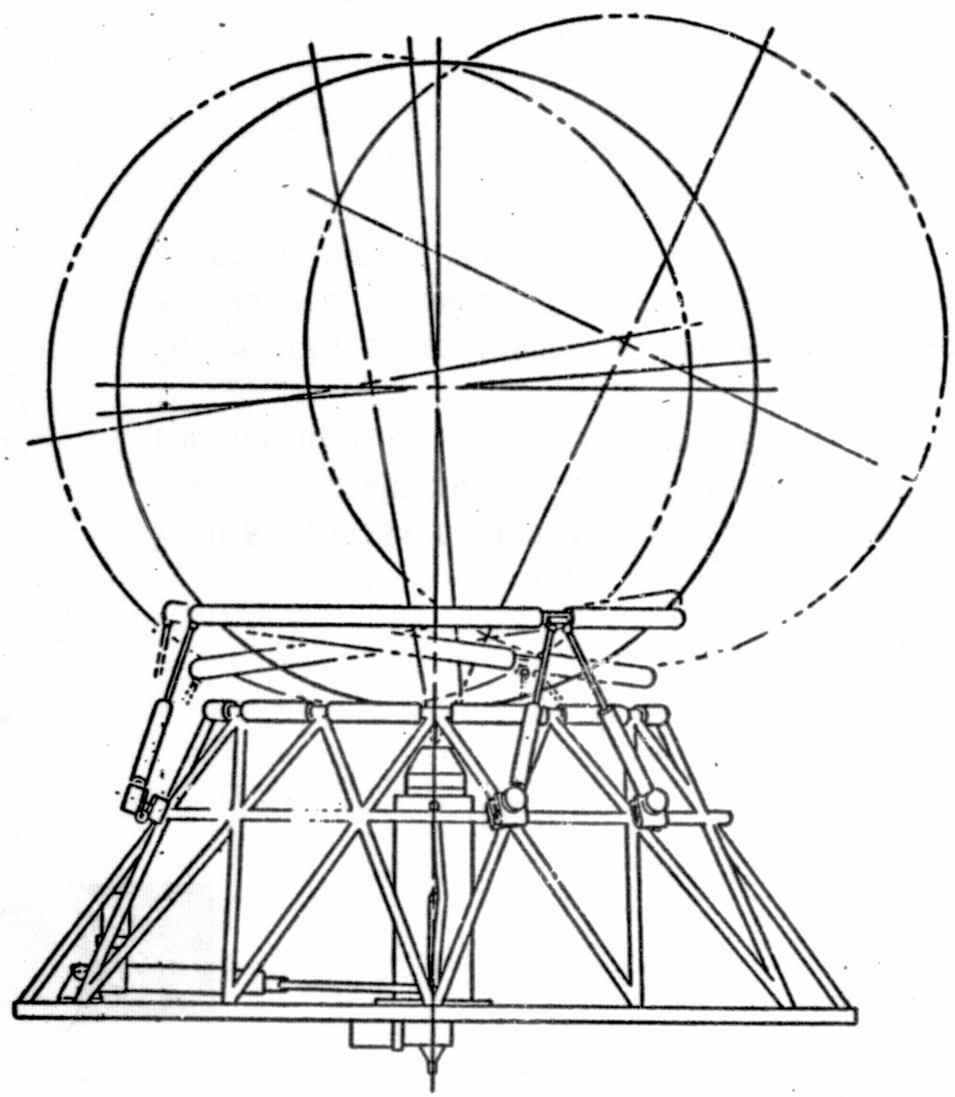
70-11-46

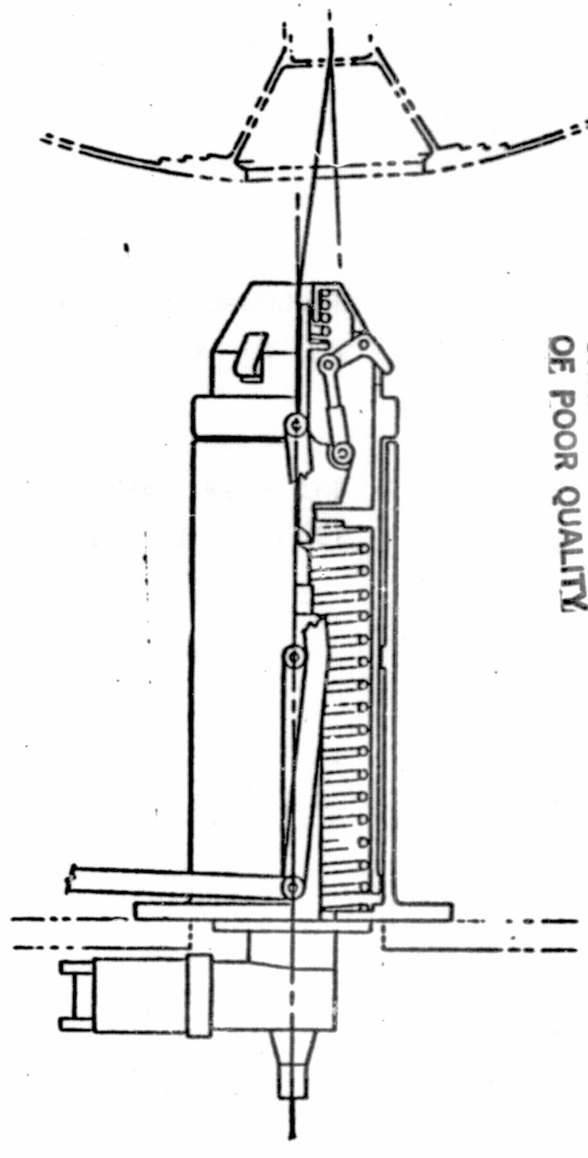
DURING RETRIEVAL, THE SPHERICALLY SHAPED SATELLITE IMPACTS A CIRCULAR DOCKING RING AND UNDER TENSION OF THE TETHER COMES TO REST CENTERED IN THE RING.

THE DOCKING PROBE IS THEN EXTENDED, ENGAGING THE DROGUE SOCKET ON THE SATELLITE AND AFTER LATCHING THE PROBE IS RETRACTED, PULLING THE SATELLITE AGAINST THE DOCKING RING AND RESISTANCE OF THE DOCKING RING SPRINGS.

THE DAMPING OF REBOUND MOTION OF THE SATELLITE IS ACHIEVED THROUGH TWO EFFECTS: (1) ABSORPTION OF THE KINETIC ENERGY BY THE DOCKING RING SPRING DAMPERS, AND (2) A TETHER TENSION PROFILE WHICH IS PROGRAMMED TO EXECUTE FAIRLY LARGE TENSIONS OF ABOUT TEN NEWTONS DURING REBOUNDS AND SMALL TENSIONS OF LESS THAN ONE NEWTON DURING REEL IN.

DOCKING ASSEMBLY AND CAPTURE DROGUE

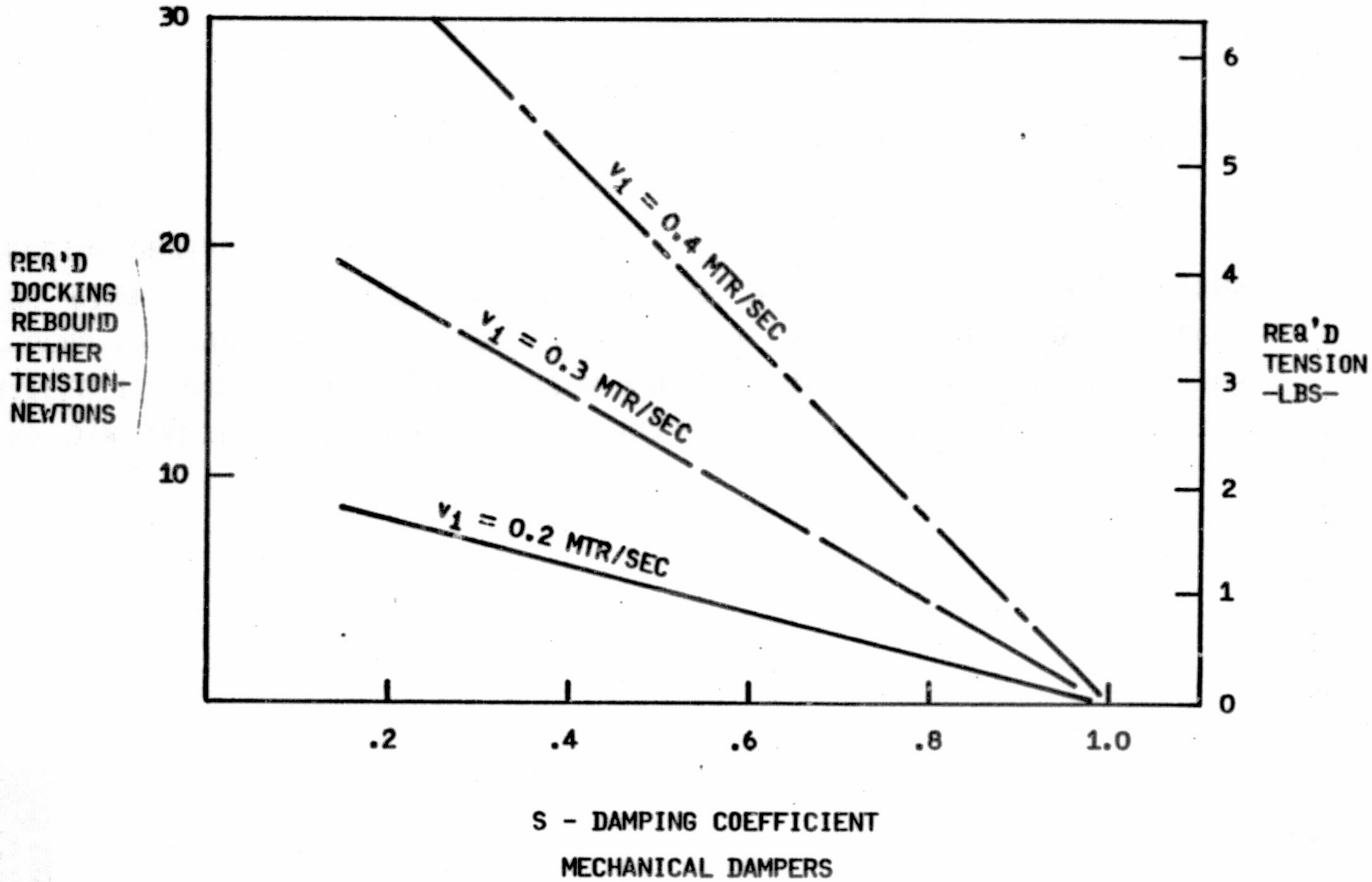




TETHER TENSION DURING DOCKING IS PROGRAMMED TO LIMIT REBOUND TO LESS THAN ONE DIAMETER OF THE DOCKING RING, THUS ENSURING IMPACT WITH THE DOCKING RING ON SUCCESSIVE BOUNCES.

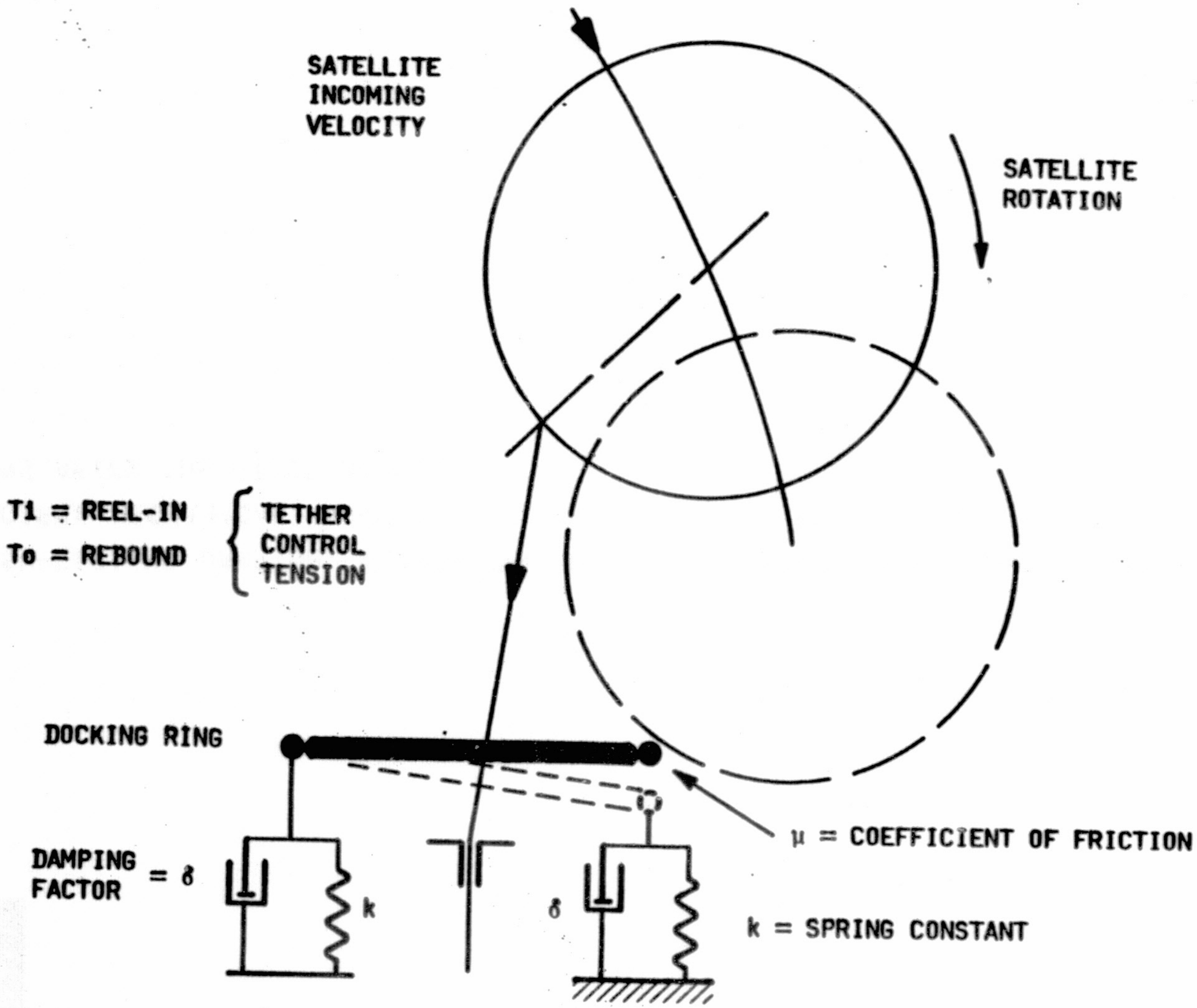
THE SYSTEM IS DESIGNED TO ACCOMMODATE IMPACT VELOCITIES OF UP TO 0.3 METERS PER SECOND. TENSION PROFILES CAN BE ADJUSTED TO ACCOMMODATE SELECTED IMPACT VELOCITIES.

DOCKING PULL-IN TENSION REQUIRED TO RESTRICT FIRST REBOUND TO LESS THAN ONE METER (500KG SATELLITE)



TWO DIMENSIONAL SIMULATION WAS FORMULATED TO ANALYZE BEHAVIOR OF THE SATELLITE AND DOCKING RING DURING FINAL CAPTURE. THE SIMULATION INCLUDED DYNAMIC EFFECTS OF FRICTION BETWEEN THE SATELLITE AND THE DOCKING RING AND THE RIGID BODY MOTION OF THE SATELLITE UNDER VARIOUS TENSION PROFILES.

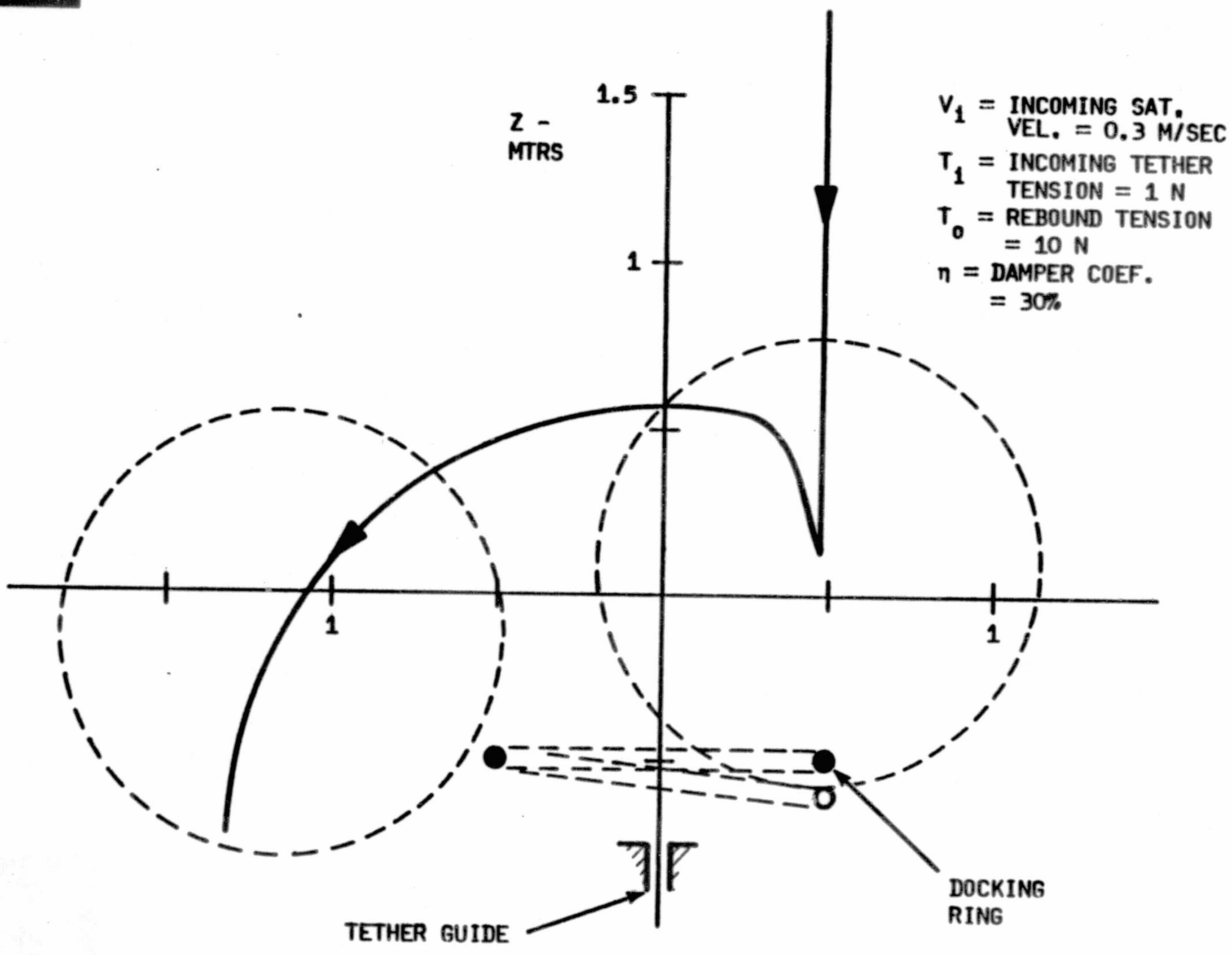
DOCKING SIMULATION GEOMETRY



P30

INSUFFICIENT DAMPING, EITHER DUE TO TOO LOW REBOUND TENSION OR INSUFFICIENT MECHANICAL DAMPING, ALLOWS THE SATELLITE TO MISS THE DOCKING RING AFTER THE FIRST BOUNCE.

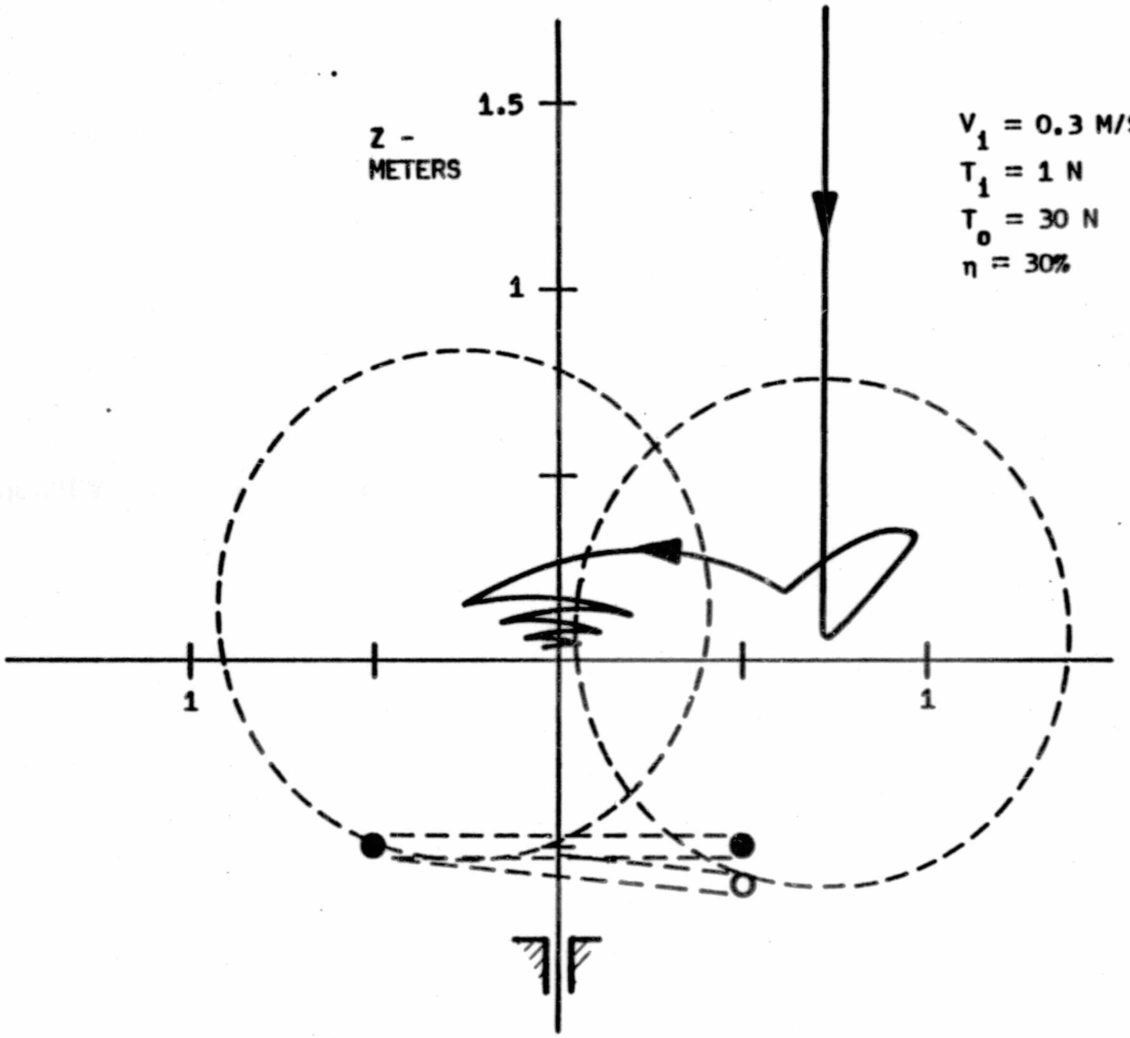
SATELLITE DOCKING – INSUFFICIENT DAMPING



TO-11

WITH SUFFICIENT DAMPING THE SATELLITE SETTLES INTO DOCK POSITION.

SATELLITE DOCKING – 30 N PULL IN TENSION



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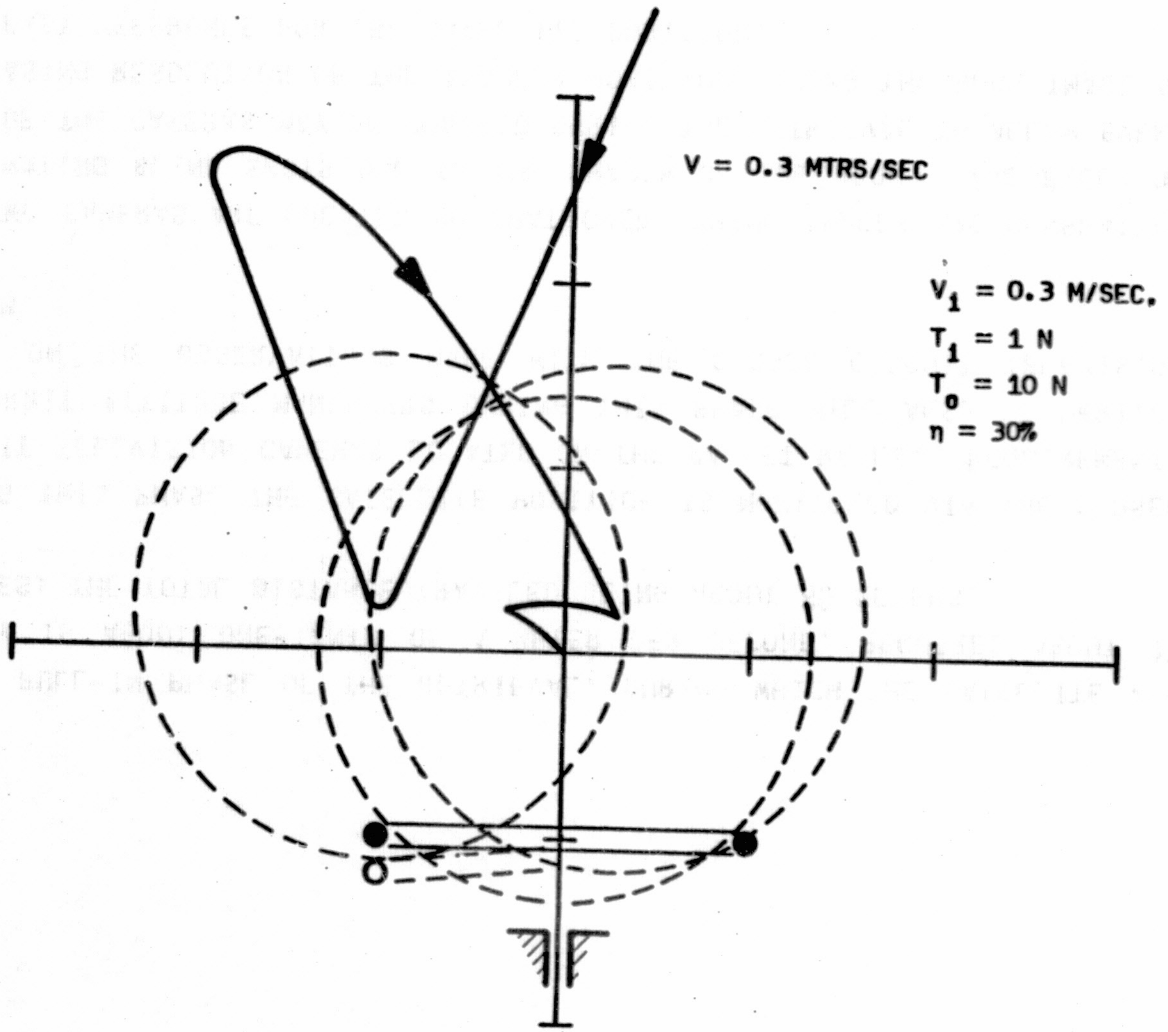
DECREASING REBOUND TENSION RESULTS IN WIDER REBOUND EXCURSION.

F80-10

SATELLITE DOCKING – 10 NEWTON –REBOUND TENSION

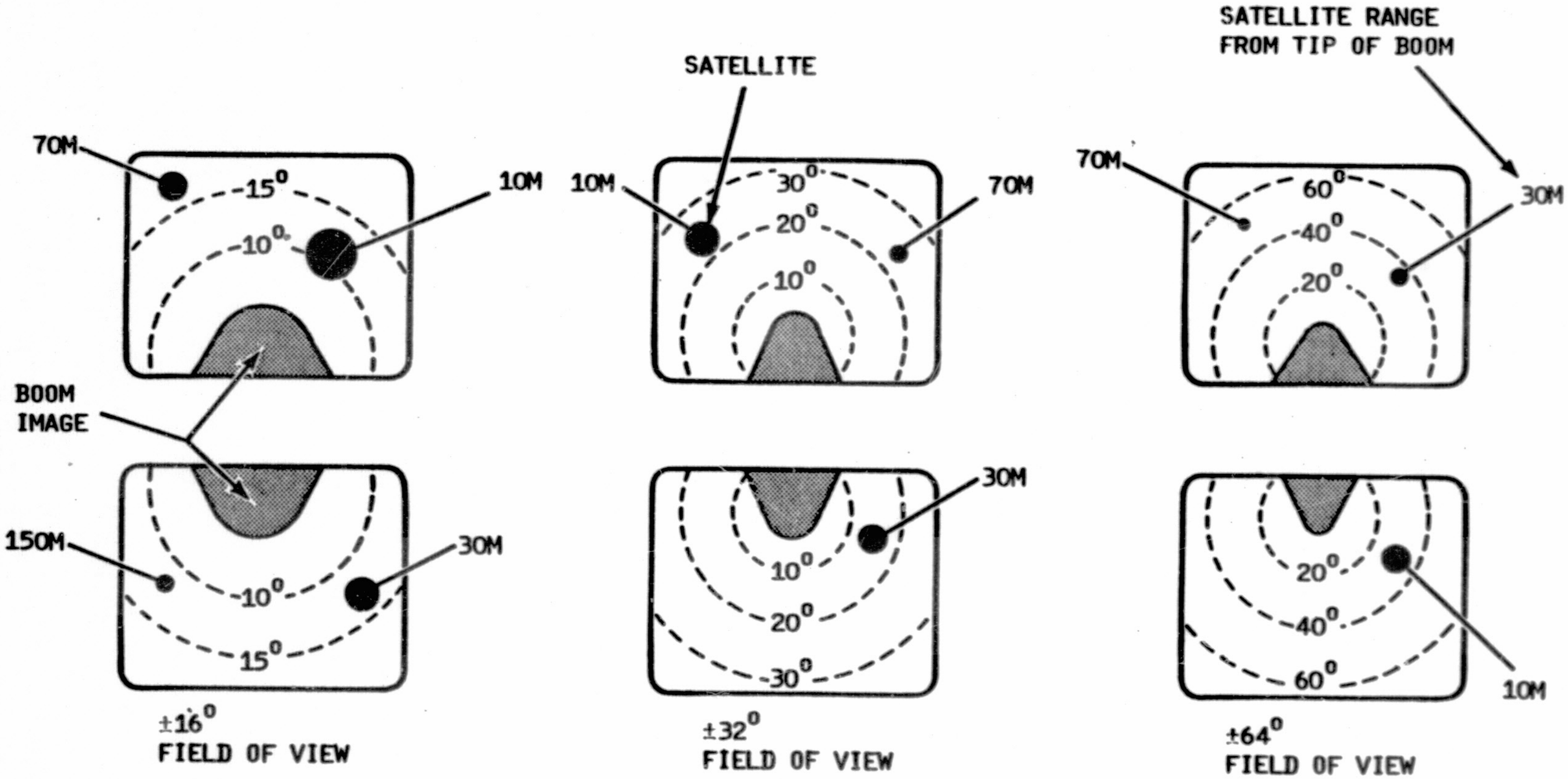


FINAL PULL-IN PHASE OF THE RETRIEVAL, DURING WHICH THE SATELLITE VELOCITY IS ABOUT ONE-TENTH OF A METER PER SECOND, REQUIRES ABOUT 13 MINUTES; THE TOTAL DISTANCE TRAVELED BEING ABOUT 80 METERS.

DURING THIS PHASE THE SATELLITE POSITION IS MONITORED VIA THE CLOSED CIRCUIT TELEVISION CAMERAS LOCATED ON THE PALLET RAILS. REQUIREMENTS FOR ORBIT ATTITUDE MANEUVERS DURING THIS PHASE WILL ALSO BE DERIVED BASED ON THE OBSERVATIONS MADE WITH THE CLOSED CIRCUIT TELEVISION SYSTEM.

THE TWO CAMERAS ARE LOCATED SO THAT OVERLAPPING IMAGES ARE GENERATED, ELIMINATING BLIND SPOTS DUE TO THE SHADOW OF THE BOOM. THE FIELD OF VIEW OF THE CAMERAS MAY BE CHANGED DURING THE RETRIEVAL TO ALLOW EVER-INCREASING RESOLUTION OF THE ANGULAR POSITION, USING THE BOOM IMAGE AS AN OFFSET REFERENCE FOR THE SATELLITE POSITION.

CLOSED CIRCUIT TELEVISION IMAGES - CAMERAS LOCATED ON PALLET RAILS



DOCKING DYNAMICS - STUDY RESULTS

SATELLITE CAPTURE WILL OCCUR UNDER THE FOLLOWING IMPACT CONDITIONS:

- SATELLITE VELOCITIES UP TO 0.4 MTR/SEC
- OFF-AXIS INCIDENCE ANGLES LESS THAN ±50°
- MISS DISTANCES LESS THAN 1.2 METERS
- WITH DOCKING TENSION AFTER FIRST BOUNCE OF:
  - (A) LESS THAN 3 NEWTONS (~0.5 POUND) DURING REEL-IN
  - (B) MORE THAN 30 NEWTONS (~6.5 POUNDS) DURING REBOUND
- DOCKING DAMPERS REMOVE 50 PERCENT OF ENERGY/BOUNCE
- OTHER COMBINATIONS OF DAMPING COEFFICIENT, INCOMING VELOCITY, AND TETHER TENSION MAY BE USED

F80-10

1200 - ORBITER, SPACELAB, TSS SOFTWARE REQUIRMENTS DEFINITION

ORIGINAL PAGE IS OF POOR QUALITY

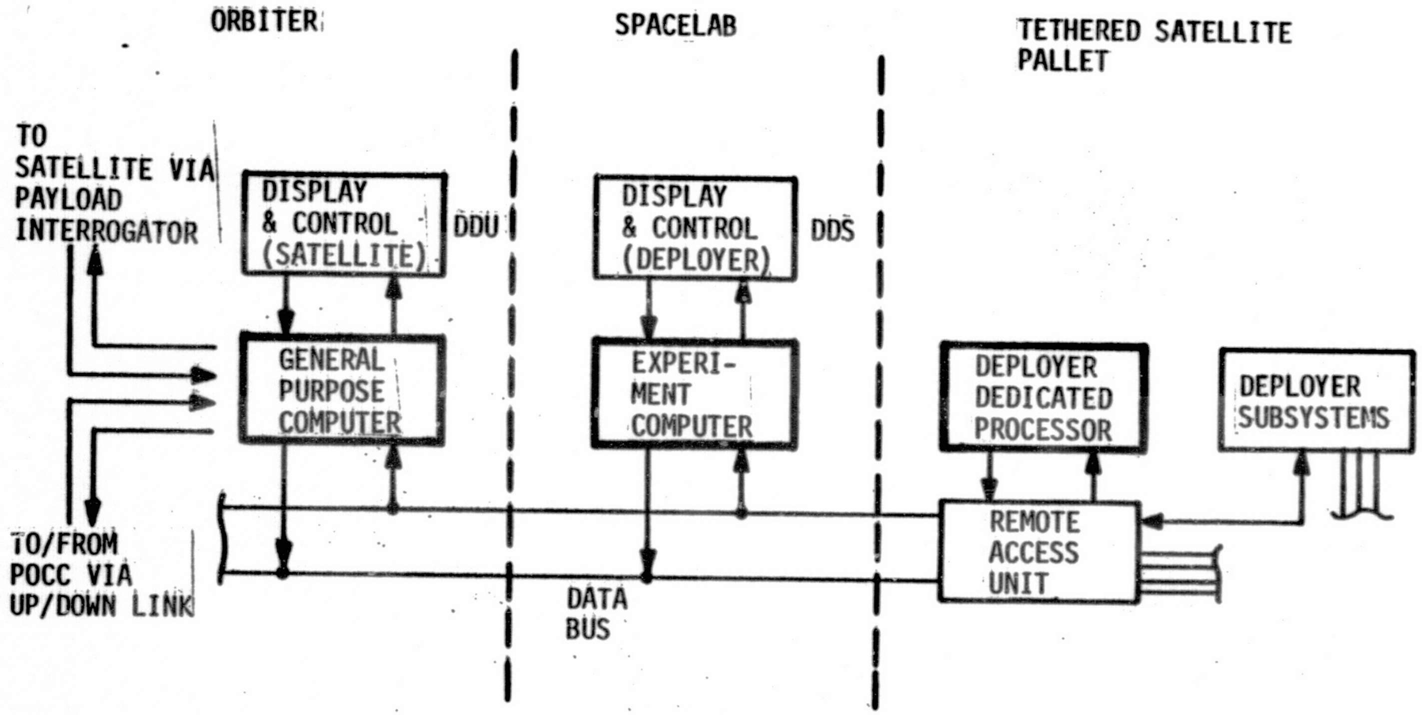
THE TETHERED SATELLITE SOFTWARE FUNCTIONS ARE LOCATED IN THREE AREAS:

(1) DATA FROM THE SATELLITE VIA THE ORBITER PAYLOAD INTERROGATER ARE HANDLED TOGETHER WITH THE ORBITER SATELLITE NAVIGATIONAL DATA, BY THE ORBITER GENERAL PURPOSE COMPUTER.

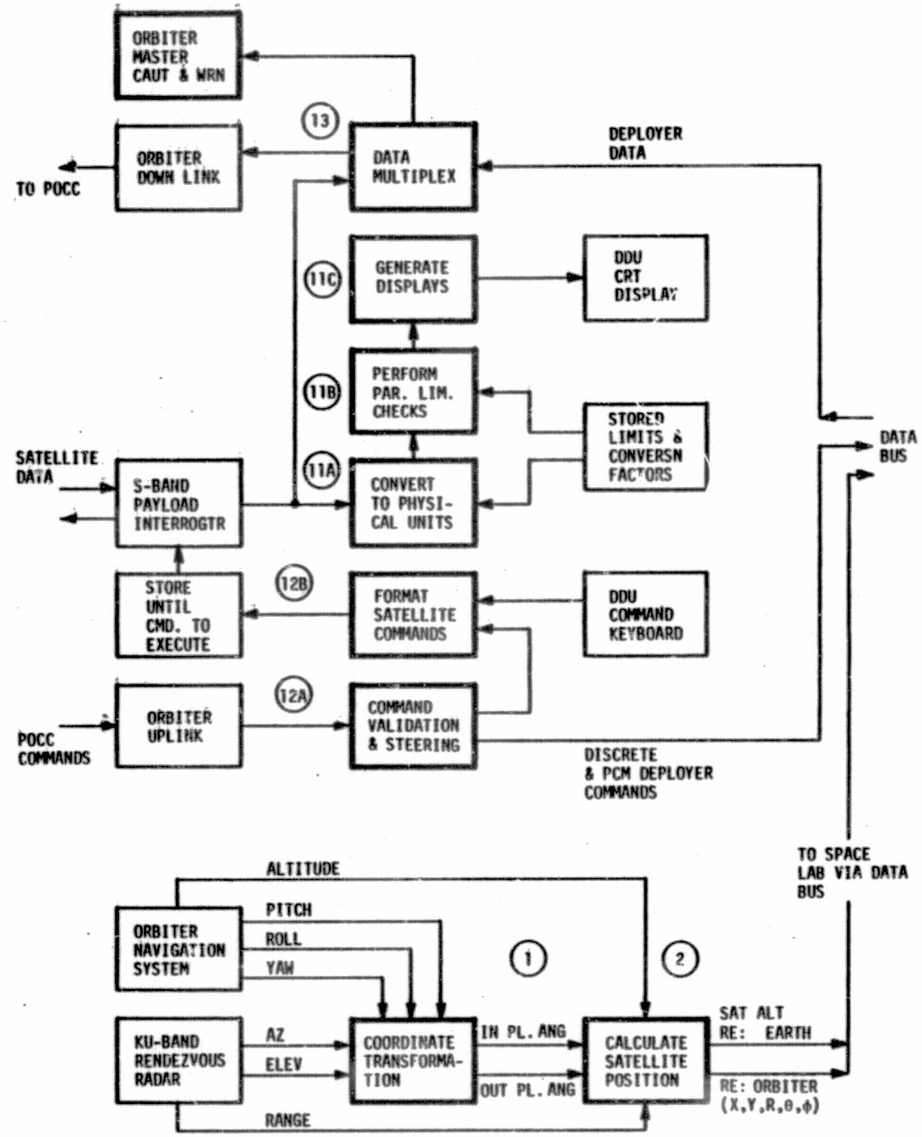
(2) HOUSEKEEPING DATA FROM THE DEPLOYER ARE HANDLED IN A SPACELAB EXPERIMENT COMPUTER LOCATED IN THE IGLOO.

(3) SPECIAL PURPOSE DATA HANDLING RELATED TO THE TETHER CONTROL AND THE DEPLOYER OPERATIONAL STATUS IS HANDLED BY A DEDICATED PROCESSOR LOCATED ON THE TSS PALLET.

TSS SOFTWARE FUNCTIONAL LOCATIONS



ORBITER SOFTWARE FUNCTIONS



ORBITER SOFTWARE REQUIREMENTS

BLK. NO.	SOFTWARE FUNCTION	RATE/ SPEED	PRECISION	ALGORITHM REMARKS
12A	EXECUTE SATELLITE COMMANDS FROM ORBITER UP-LINK. TOTAL OF 15 DISCRETE COMMANDS (64 AVAILABLE)	2 KBPS. AS REC'VD AND VALIDATED	16 BIT AND PARITY	STORE FOR TRANSMISSION TO SATELLITE (VIA S-BAND PAYLOAD INTEROGATOR) UPON OPERATOR COMMAND FROM ORBITER DATA DISPLAY UNIT (DDU)
12B	EXECUTE SATELLITE COMMANDS FROM DDU. SAME GROUP AS IN 12A.	2 KBPS	16 BIT AND PARITY	
11A	DECOMMUTATE SATELLITE HOUSEKEEPING DATA (FROM S-BAND PAYLOAD INTERROGATOR). 36 ANALOG CHANNELS (64 AVAIL.) 10 DISCRETE INDICATORS (32 AVAIL.)	1/SEC	8 BIT	
11B	CONVERT EACH ANALOG OUTPUT FROM BLK. 11A TO PHYSICAL UNITS. STORE IN DISPLAY MATRIX. STORE DISCRETE DATA OUTPUTS IN DISPLAY MATRIX AS SATELLITE MODE STATUS INDICATORS. 10 INDICATORS (32 AVAILABLE)	1/SEC	8 BIT	$X_n = A_n + B_n X_{n\,raw}$. A&B ARE COEFFICIENTS LOADED DURING INITIALIZATION.

ORBITER SOFTWARE FUNCTIONAL REQUIREMENTS (cont,d)

BLK. NO.	SOFTWARE FUNCTION	SPEED	PRECISION	ALGORITHM/REMARKS
11B	PERFORM LIMIT CHECKS ON ANALOG PARAMETERS FROM BLOCK 11A. FLAG OUT-OF-LIMITS CONDITIONS	1/SEC	8 BIT	$X_{n-min} < X_n < X_{nmax}$? LIMITS ENTERED AND STORED AS INITIALIZATION DATA
11C	GENERATE DDU CRT DISPLAYS - TOTAL OF 2 - FROM OUTPUT OF BLK 11A and 11B.			PER DDU USERS MANUAL REQUIREMENTS SEE ACCOMPANYING FIGURES
13	MULTIPLEX SATELLITE AND DEPLOYER DATA ON TO ORBITER DOWNLINK DATA STREAM FOR REAL-TIME TRANSMISSION TO POCC.	16 KBPS	8 BIT	PER ORBITER AND DOWNLINK REQUIREMENTS
1	CALCULATE IN-PLANE AND OUT-OF PLANE ANGULAR POSITION OF SATELLITE RELATIVE TO ORBITER, USING DATA FROM Ku-BAND REDESVOUS RADAR AND ORBITER ATTITUDE DETERMINATION SYSTEM.	1/MIN	8 BIT (1 DEG.)	$\theta_{in-pl} = TAN^{-1}\frac{X}{Z}$; $\phi_{oo-pl} = TAN^{-1}\frac{Y}{Z}$ Where AZ and El are RADAR GIMBAL ANGLES AND $\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} \text{F(PITCH} \\ \text{ROLL,YAW)} \\ \text{OR ORBITER} \end{bmatrix} \begin{bmatrix} \text{Cos Az Cos El} \\ \text{Sin Az Cos El} \\ \text{Cos El} \end{bmatrix}$
2	CALCULATE IN-PLANE AND OUT OF PLANE DISTANCES IN Km. MULTIPLEX ON TO DATA BUS TO DEPLOYER			ORBITER ATTITUDE MATRIX RE-LOCAL VERTICAL AND VELOCITY VECTOR.

SATELLITE-TO-ORBITER DATA SUMMARY

ANALOG DATA (8-BIT ENCODING)	
HOUSEKEEPING	25 CHANNELS
EXPERIMENT	11 CHANNELS
SPARES	12 CHANNELS
TOTAL	48
SERIAL DIGITAL DATA (PCM)	
HOUSEKEEPING	-
EXPERIMENT	8 KBPS @ 100 KM
BI-LEVEL INDICATORS	
HOUSEKEEPING	10
EXPERIMENT	12
SPACES	10

ORBITER-TO-SATELLITE COMMAND SUMMARY (VIA PAYLOAD INTERROGATOR LINK)

DISCRETE COMMANDS

SATELLITE CONTROL (HOUSEKEEPING)	15
SATELLITE EXPERIMENT CONTROL	15
SPARES (UNASSIGNED)	24
TOTAL (TO BE RESERVED)	64

SERIAL COMMANDS

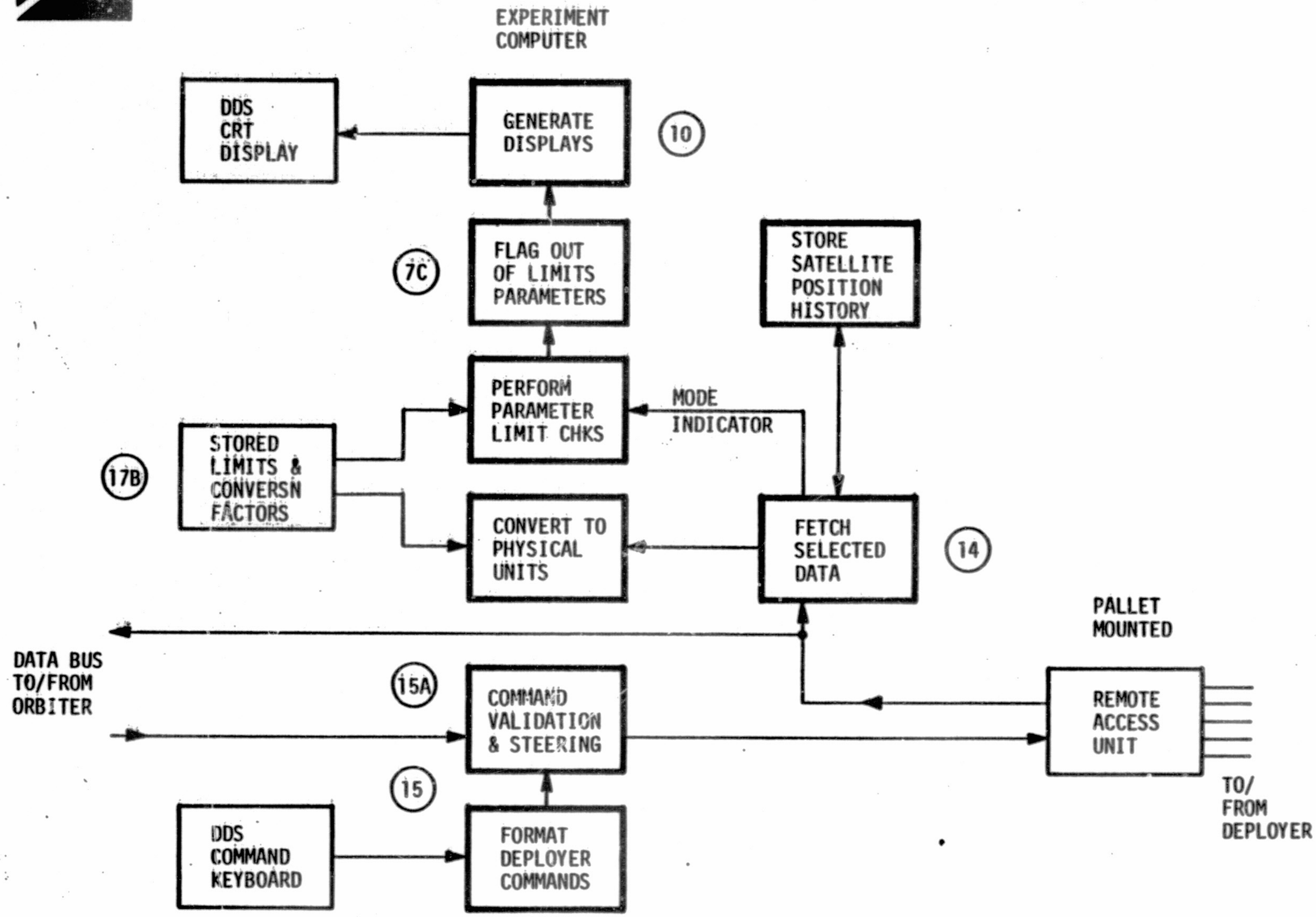
SATELLITE	0
EXPERIMENT	EXPERIMENT DEPENDENT
SPARES (UNASSIGNED)	8
TO BE RESERVED	8

PCM COMMANDS

EXPERIMENT DEPENDENT

SPACELAB SOFTWARE FUNCTIONS, EXECUTED BY THE SPACELAB COMPUTER, GENERATE DISPLAYS, EXECUTE CONTROL COMMANDS, AND MONITOR THE STATUS OF THE DEPLOYER.

SPACELAB SOFTWARE FUNCTIONS



SPACELAB SOFTWARE REQUIREMENTS

BLK. NO.	SOFTWARE FUNCTION	RATE/ SPEED	INPUTS	OUTPUT(S)	ALGORITHM/REMARKS
15	FORMAT DEPLOYER COMMANDS FROM DDS. TOTAL OF 41 DISCRETE CMDS. (64 AVAILABLE)	AS KEYED	OUTPUT OF DDS KEY-BOARD	16-BIT (RAU) COMMAND WORDS	PER DDS TO CMD TRANSLATION REQUIREMENTS PER SEC. 4.3.1.2 OF MDC G6854B, SPACELAB PROGRAM SOFTWARE USERS GUIDE.
15A	EXECUTE DEPLOYER COMMANDS FROM UPLINK (SAME COMMANDS AS IN 15.)	AS REC-EIVED FROM ORBITER GPC	FORMATED CMDS. FROM ORBITER GPC (UPLINK)	"	
14	FETCH DEPLOYER HOUSEKEEPING DATA FROM S/L DATA BUS FOR ON-BOARD PROCESSING. 46 ANALOG CHANNELS (64 AVAILABLE)	1/SEC	TSS RAW OUTPUT	DATA INPUT TO BLOCK (7A)	DECOMUTATION CLOCKING PATTERN
7A1	CONVERT EACH ANALOG OUTPUT FROM BLOCK (14) (ABOVE) TO PHYSICAL UNITS	1/SEC	DATA FROM BLOCK (14)	8 BIT WORDS, INPUT TO BLK (7B)	$X_r = A_n + B_n X_{raw}$ WHERE A&B FOR EACH ANALOG PARAMETER ARE LOADED AS INITIALIZATION DATA. (EQUIVALENT TO SPECIFYING PHYSICAL VALUES CORRESPONDING TO LIMITS OF $\pm$ 5V RANGE).

SPACELAB SOFTWARE REQUIREMENTS (cont'd)

BLK. NO.	SOFTWARE FUNCTION	RATE/ SPEED	INPUT/ SOURCE	OUTPUT/ DESTINATION	ALGORITHM/REMARKS
7A2	STORE BILEVEL DATA FROM BLK 14, IN MATRIX FOR USE IN FURTHER PROCESSING. 37 INDICATORS (TOTAL OF 64 AVAILABLE)	1/SEC	DEPLOYER RAU	EXP. COMPUTER	
7B,7C	PERFORM LIMIT CHECKS ON ANALOG PARAMETERS, OUTPUT FROM BLOCK 7A1. 46 PARAMETERS (64 AVAIL). TAG OUT-OF-LIMIT WORDS	1/SEC	8 BIT DATA	DISPLAY DATA BLOCK- EXP. COMPUTER	$X_{n-min} < X_n < X_{nmax}$? LIMITS ENTERED AND STORED AS PART OF INITIALIZATION DATA.
10	GENERATE CRT DISPLAYS-TOTAL OF 5 DISPLAYS PER ACCOMPANYING DIAG. (TOTAL 20 MODE STATUS INDICATORS AND 37 PARAMETERS)		OUTPUT OF BLKS. 7A2, 7B and 7C	CRT	PER MDC G6854B, SPACELAB PROGRAM USERS GUIDE AND SLP 2104 - S/L ACCOMMODATION HNDBK SECT. 4.4.6.3
17B	LOAD INITIALIZATION DATA INTO SPACELAB EXP. COMP MEMORY.				
	PROCESSING PROGRAM				PER OUTLINED ABOVE
	ALGORITHM COEFICIENTS				ABOUT 150 VALUES (8-BIT-SIG)
	PARAMETER LIMITS				ABOUT 150 VALUES (8-BIT-SIG)

SPACELAB SOFTWARE FUNCTIONAL REQUIREMENTS (cont'd)

BLK. NO.	SOFTWARE FUNCTION	RATE/ SPEED	PRECISION	ALGORITHM/REMARKS
19	SATELLITE POSITION HISTORY. STORE IN-PLANE & OUT-OF-PLANE ANGLES AND RANGE DATA, FOR TOTAL OF 4 HOUR PERIOD	3/MIN.	8 BIT	3X20X4 = 240 WORDS RETRIEVABLE AS DEPLOYER PCM TELEMETRY DATA

DEPLOYER COMMAND AND DATA HANDLING SUMMARY (VIA PALLET RAU)

DISCRETE COMMANDS

ASSIGNED	41
SPARES	23
TOTAL (RESERVED)	64

BILEVEL STATUS INDICATORS

ASSIGNED	21
SPARES	11
TOTAL	32

ANALOG STATUS INDICATORS

ASSIGNED	45
SPARES	19
TOTAL	64

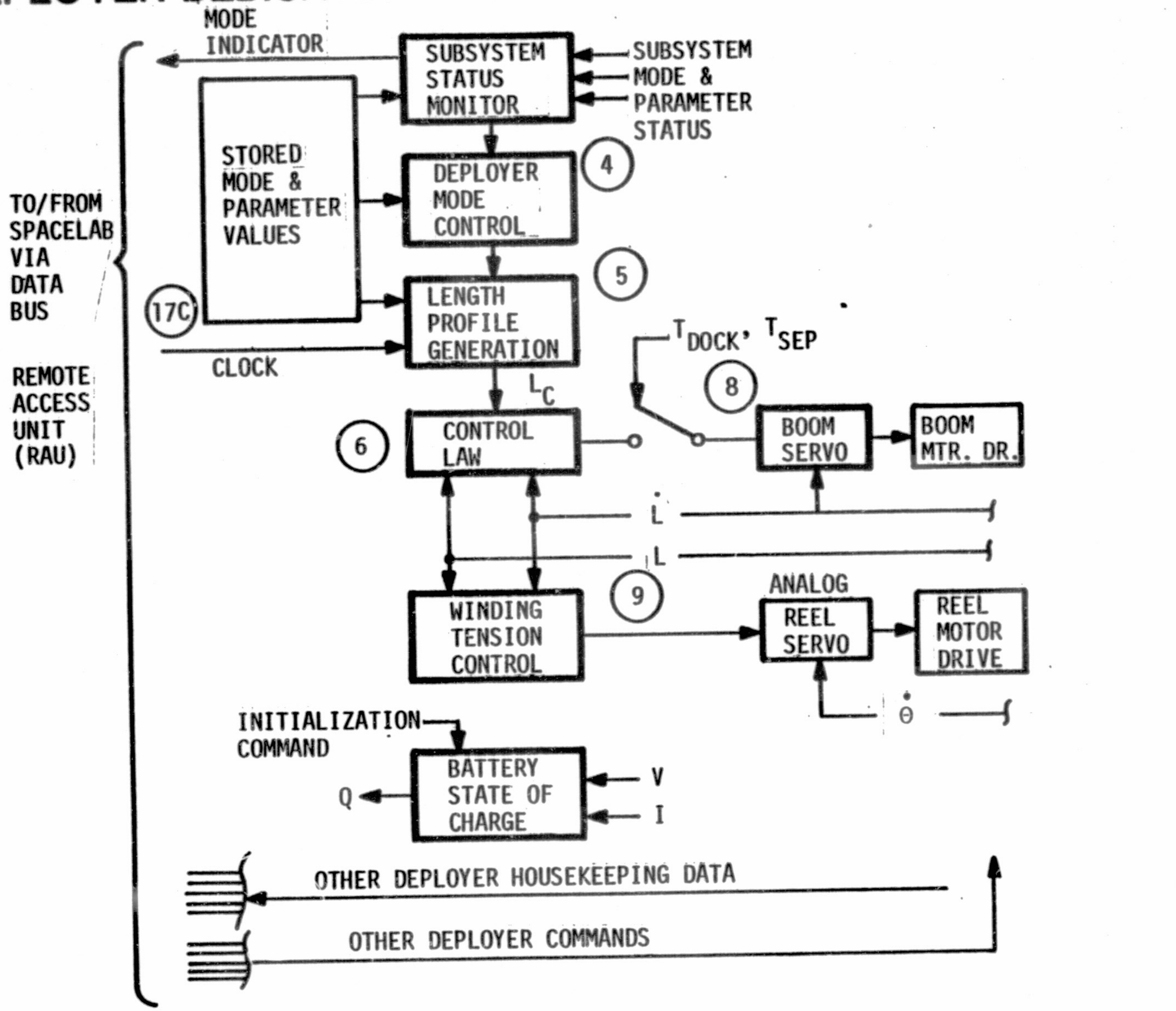
TYPICAL DISPLAY GROUP - TETHER CONTROL - NO. 1

OPER. MODE - ON (XXXXX)	DEPLOYER MODE - PAYOUT (XXXXX)
TETHER LENGTH XX KM.	TETHER RATE - XX M/SEC.
TETHER TENSION XX N.	OUT-OF-LIMITS GROUP 0 (1, 2, 3, 4, 5)

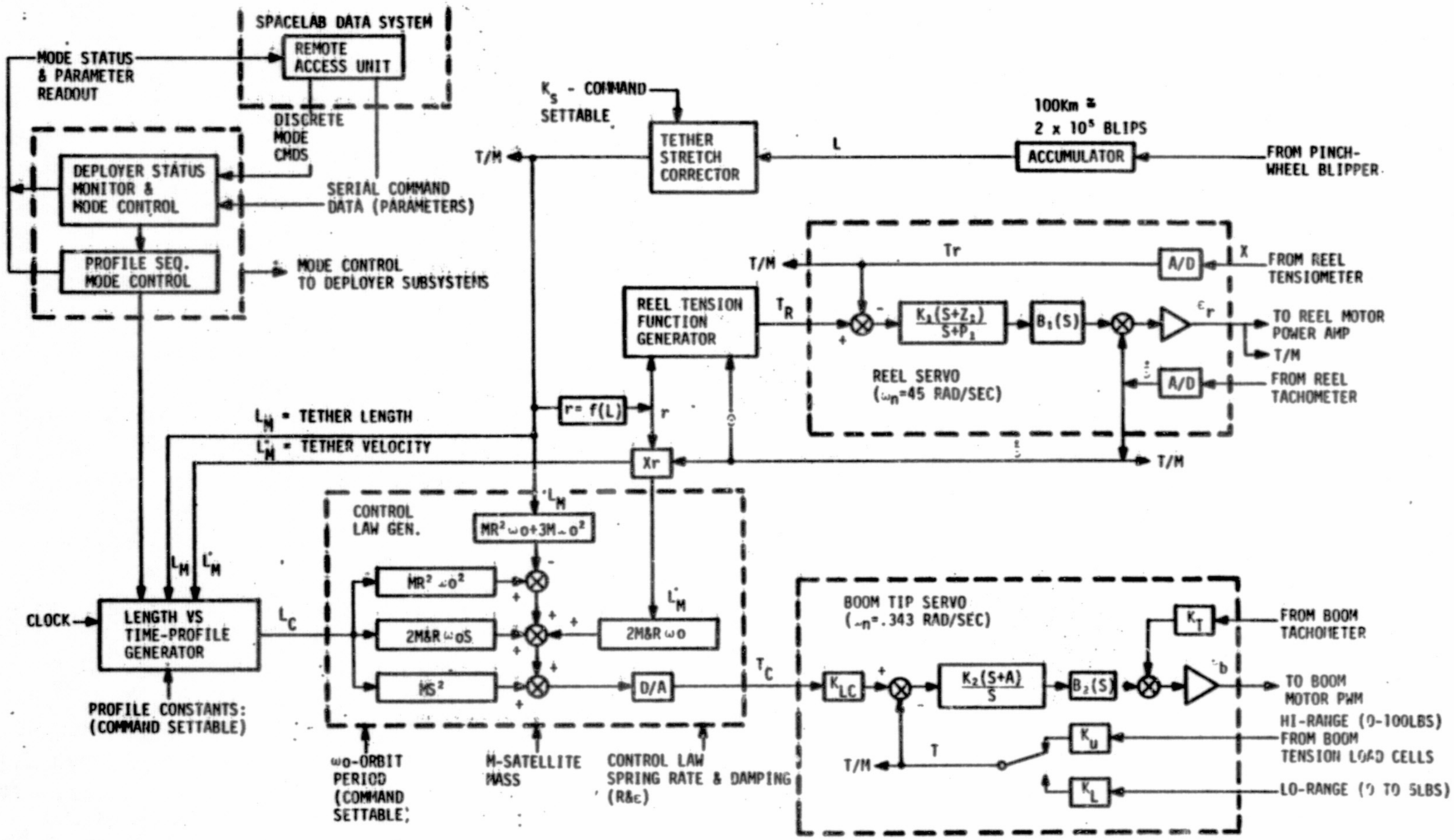
REEL TENSION	XX	N	(XX - XX)
REEL SERVO ERROR	XX	V	(XX - XX)
REEL MOTOR CURRENT	XX	A	(XX - XX)
REEL BRAKE	OFF(ON)		
BOOM SERVO ERROR	XX	V	(XX - XX)
BOOM MOTOR CURRENT	XX	A	(XX - XX)
BOOM BRAKE	OFF(ON)		
BOOM TENSION	XX	N	(XX - XX)

SOFTWARE FUNCTIONS PERFORMED IN THE TSS DEPLOYER DEDICATED PROCESSOR ARE PECULIAR TO THE TETHERED SATELLITE SYSTEM. THE FUNCTIONS ARE COMPATIBLE WITH WELL-ESTABLISHED DIGITAL PROCESSING TECHNIQUES AND THE COMPUTING SPEED AND STORAGE REQUIREMENTS ARE MODERATE.

DEPLOYER DEDICATED PROCESSOR SOFTWARE FUNCTIONS



TETHERED SATELLITE DEPLOYER DEDICATED PROCESSOR



DEPLOYER SOFTWARE FUNCTIONAL REQUIREMENTS

BLK. NO.	SOFTWARE FUNCTION	RATE/ SPEED	PRECISION	ALGORITHM/REMARKS
4	DEPLOYER MODE CONTROL. CONTROLS AND INTERLOCKS STATES OF DEPLOYER SUB-SYSTEMS IN RESPONSE TO OPERATOR COMMANDS, TIME-LINE SEQUENCES, OR AUTOMATICALLY SENSED OUT-OF-LIMITS CONDITIONS. 6 DIFFERENT DEPLOYER MODES 6 DIFFERENT REELING MODES	1/SEC	-	LOGIC STATEMENTS INTERLOCKING RELAY AND LOGIC STATES AND SELECTING PARAMETER VALUES CONFIRMS MODE STATES BY TESTING BI-LEVEL SUBSYSTEM INDICATORS AGAINST MODE CONFIGURATIONS
5A	GENERATE TETHER LENGTH VS. TIME COMMAND PROFILES:			
	START - PATCH (AUTOMATICALLY) TO RUN PROFILE WHEN $\dot{L}_s = \dot{L}_o$ FOR NEXT PROFILE			$L_c = L_{os} \pm \dot{L}_s (1-e^{-\alpha_s t}) t$
	RUN W/EXP. CHANGING RATE			$L_c = L_{oe} e^{\pm \alpha_e t}$
	RUN-CONSTANT VELOCITY			$L_c = L_{oc} \pm \dot{L}_{oc} t$
	STOP - AUTOMATIC OR COMMANDED SHUTDOWN			$L_c = L_{op} \pm \dot{L}_i e^{-\alpha_p t} t$

α_x = VEL, CHANGE RATE, L_{ox} = LENGTH AT START OF SEGMENT

$\dot{L}_i$ = INSTANTANEOUS MEASURED VELOCITY AT START OF PROFILE SEGMENT

	HARMONIC GENERATORS - 2 EACH (LENGTH COMMAND MODULATION)			$\Delta L_c = A \sin(K\omega_o t + \beta)$ AMPLITUDE, PHASE, AND HARMONIC BY GROUND COMMAND

SOFTWARE REQUIREMENTS DEFINITION–STUDY RESULTS

- ALL SPECIAL-PURPOSE SOFTWARE FUNCTIONS, PECULIAR TO TSS ARE CONFINED TO THE DEPLOYER DEDICATED DIGITAL PROCESSOR.
- SPACELAB SOFTWARE FUNCTIONS INCLUDE DEPLOYER DATA AND COMMAND MULTIPLEXING, CONVERSION TO PHYSICAL UNITS, LIMIT CHECKS AND DISPLAY OF DEPLOYER HOUSEKEEPING PARAMETERS.
- ORBITER SOFTWARE FUNCTIONS INCLUDE SATELLITE DATA AND COMMAND HANDLING, CONVERSION TO PHYSICAL UNITS, LIMIT CHECKS AND DISPLAY OF SATELLITE DATA, AND CALCULATION OF ORBITER AND SATELLITE NAVIGATION PARAMETERS.

1300 – TETHER MATERIALS EVALUATION

- MATERIAL SELECTION
- FABRICATION AND SPLICING

SELECTION OF TETHER MATERIAL IS INFLUENCED BY SUCH FACTORS AS:

- COMPATIBILITY WITH THE SPACE ENVIRONMENT
- AVAILABILITY OF MATERIAL USING ESTABLISHED FABRICATION TECHNIQUES
- COMPATIBILITY WITH ESTABLISHED REELING (WINDING) TECHNIQUES AND MECHANISMS
- STIFFNESS (LACK THEREOF) - COMPATIBILITY WITH TETHER CONTROL MECHANISMS
- STRENGTH PROPERTIES AND PACKING DENSITY OF THE STORED TETHER

F80-10

CONCLUSIONS – TETHER MATERIAL SELECTION

- BEST MATERIAL IS UNEMPREGNATED, BRAIDED KEVLAR 29
- RIGID MATRIX (EPOXY) IS ONLY USEABLE IF A PERFECT WIND REELER IS USED
- PERFECT WIND REELER IS USEABLE ONLY FOR LIMITED WINDING DEPTHS & WITH IDEALLY UNIFORM, SMOOTH TETHERS
- OTHER TETHER MATERIALS, POSSIBLY USEABLE IN SHORT LENGTHS OR FOR SPECIAL APPLICATIONS, BUT GENERALLY INFERIOR TO KEVLAR
    - TITANIUM STRANDED CABLE
    - STEEL STRANDED CABLE
    - S-GLASS IN EPOXY MATRIX
- BORON AND GRAPHITE ARE NOT GOOD CANDIDATE MATERIALS AT THIS TIME
- EITHER KEVLAR OR S-GLASS TETHERS CAN BE MADE CONDUCTIVE (INSULATED) BY INTERWEAVING A COPPER CONDUCTOR

TETHER MATERIAL EVALUATION METHOD

- MAXIMUM SATELLITE MASS USEABLE WITH SPECIFIC TETHER MATERIALS AND CONFIGURATIONS WAS DETERMINED BY COMPUTER SIMULATION
  - LOADING AND STRESSES WERE CALCULATED AT POINTS ALONG THE TETHER, INCLUDING THOSE IN THE REELING MECHANISM
  - DERATING FACTORS WERE IN APPLIED FOR, ABRASION, WEAR, TEMPERATURE AND UV DEGRADATION

- PARAMETERS USED IN THE ANALYSIS
  - TETHER LENGTH = 100 KM.
  - ACCELERATION 0.2 M/SEC^2
  - FACTOR OF SAFETY = 3.0

FACTORS AFFECTING TETHER MATERIAL SELECTION

LOAD REQUIREMENTS - SATELLITE & TETHER MASS & LOADS DURING REELING (ACCELERATION)

ABRASION & FATIGUE DURING USE

COMPATIBILITY WITH REELING SYSTEM
- STIFFNESS
- USEABLE BEND RADII
- NEED FOR PERFECT WIND

DEGRADATION FROM
- UV EXPOSURE
- TEMPERATURE
- AGING

CANDIDATE TETHER MATERIALS – DEGRADATION FACTORS

	DISTANCE ALONG TETHER FROM ORBITER - KM	DEGRADATION FACTORS U/V	TEMP	ABRASION
BRAIDED, UNEMPREGNATED KEVLAR	0	0.8	1.0	0.8
	100	0.8	0.8	1.0
S-GLASS IN EPOXY MATRIX, POLYURETHANE SHEATH	0	1.0	1.0	1.0
	100	1.0	0.85	1.0
7 X 7 TITANIUM CONTRAHELICALLY WOUND	0	1.0	1.0	1.0
	100	1.0	0.9	1.0
7 X 7 STAINLESS STEEL CONTRAHELICALLY WOUND	0	1.0	1.0	1.0
	100	1.0	0.9	1.0

PROPERTIES OF CANDIDATE TETHER MATERIALS

CONFIGURATION	TITANIUM 7x7 STRANDED CONTRAHELICAL		STEEL 7x7 STRANDED CONTRAHELICAL		S-GLASS POLYURTH SHEATH-EPOXY MATRIX		KEVLAR UNEMPREGNATED BRAID			
DIAMETER: • INCHES	0.047	0.062	0.047	0.062	0.040	0.050	0.045	0.050	0.065	0.085
• MILLIMETERS	1.19	1.57	1.19	1.57	1.01	1.27	1.19	1.27	1.65	2.16
FILAMENT DIAMETER (INCHES)	0.0055	0.0076	0.0055	0.0076	0.030	0.040	0.0047	0.0047	0.0047	0.0047
ULTIMATE STRENGTH (KPSI)	207	193	232	216	428	351				
REEL DIAMETER-FULL-CM (60 CM WIDE)	58	76	58	76	51	61	56	71	79	102
TETHER MASS (KG)	354	630	625	1120	137	226	93	163	200	270
TYPE OF WIND	SPACED	SPACED	SPACED	SPACED	PERFECT	PERFECT	SPACED	SPACED	SPACED	SPACED

F80-10

CANDIDATE TETHER MATERIALS - LOAD CAPABILITIES

	TITANIUM		STEEL		S-GLASS		KEVLAR			
DIAMETER (MM)	1.19	1.57	1.19	1.57	1.01	1.27	1.19	1.27	1.65	2.16
BREAKING STRENGTH KG/BEND RADIUS CM	109 ∞	195 ∞	122 ∞	217 ∞	129/15 136/∞	181/15 200/∞	136/ 7.5	204/ 7.5	295/ 7.5	385/ 7.5
SPACED COIL WIND (0.5 CM BEND R.)	60	69	27	-25	-87	-313	136	204	294	385
PERFECT LAYER WIND (7.6 CM BEND R.)	106	186	116	201	122	163				
MAXIMUM SATELLITE MASS F.S. =3 (KG)	340	606	230	405	593	708	394	577	857	1114
REMARKS	NO KINKS	KINKS FOR SATELLITE >370 KG	KINKS UNDER OWN WEIGHT	KINKS UNDER OWN WEIGHT	FAILS IF CROSSOVER OCCURS (EXTENDED)	FAILS IF CROSSOVER OCCURS (EXTENDED)	ABRASION AND ULTRAVIOLET DEGRADATION REDUCES ALLOWABLE SATELLITE MASS (TAKEN INTO ACCOUNT IN ABOVE FIGURES)			

CANDIDATE TETHER MATERIALS

UNIMPREGNATED KEVLAR BRAID - ACCEPTABLE, BEST CHOICE

- LOOSELY BRAIDED LINE IS SUITED FOR MORE RELIABLE AND SIMPLER SPACE-COIL WIND
- SMALL FILAMENT DIAMETER SIGNIFICANTLY REDUCES BENDING STRESSES AT WINDING CROSSOVERS
- LOW STIFFNESS, COMPATIBLE WITH LOW-TENSION CONTROL PINCH WHEELS AND GUIDES
- AVAILABLE SUPPLIER - ESTABLISHED FABRICATION TECHNIQUES
- U/V SENSITIVE - STRENGTH MUST BE DERATED UP TO 20% FOR VERIFICATION MISSION
- SOMEWHAT ABRASION SENSITIVE - STRENGTH DERATED 20% (AT SHUTTLE END OF TETHER)
- TEMPERATURE SENSITIVE - 30% STRENGTH DERATING FOR OPERATION AT 350°F. HIGH TEMPERATURE CONDITIONS OCCUR ONLY AT SATELLITE END AND AT ALTITUDES BELOW ABOUT 130 KM.

PROPERTIES OF CANDIDATE TETHER MATERIALS CONT'D

SHEATHED S-GLASS, EPOXY MATRIX - ACCEPTABLE, BUT REQUIRES MORE COMPLEX, AND LESS RELIABLE, PERFECT-WIND REELING SYSTEM

- INSENSITIVE TO ABRASION
- SOMEWHAT SENSITIVE TO UV RADIATION (FOR LONG EXPOSURE TIMES)
- SOMEWHAT SENSITIVE TO TEMPERATURE - 15% STRENGTH REDUCTION AT $350^{O}F$
- STIFFNESS COMPLICATES TENSION-HANDLING MECHANISM USED FOR CONTROL OF LOW TENSIONS
- REQUIRED PERFECT-LAYER WINDING SYSTEM:
  - INTRODUCES HIGH STRESSES AT CROSSOVER POINTS IF A WINDING ERROR OCCURS - REQUIRING SUBSTANTIAL STRENGTH DERATING
  - INVOLVES INCREASED RISK OF WINDING ERROR AS WINDING DEPTH INCREASES

SHEATHED KEVLAR IN EXPOXY MATRIX -

- SAME AS S-GLASS, EXCEPT HAS LOWER STRENGTH

PROPERTIES OF CANDIDATE TETHER MATERIALS

UNIMPREGNATED S-GLASS BRAID - ACCEPTABLE CHARACTERISTICS

- PROPERTIES SIMILAR TO KEVLAR BRAID EXCEPT:
  - STATIC FATIGUE REDUCES STRENGTH 60-70% AFTER A FEW HOURS
  - VERY LITTLE FABRICATION EXPERIENCE

FEATURES OF CANDIDATE TETHER MATERIALS

STRANDED STEEL CABLE - ACCEPTABLE FOR SHORT TETHERS

- INSENSITIVE TO U/V RADIATION
- INSENSITIVE TO ABRASION
- MILDLY SENSITIVE TO TEMPERATURE (10% STRENGTH REDUCTION AT 350°F)
- PERFECT LAYER WIND IS NOT FEASIBLE FOR MANY LAYERS
- SPACED COIL WIND WILL CAUSE YIELDING AT CROSSOVER POINTS, WHICH WILL RESULT IN "KINKS" IN THE LINE
- VERY HEAVY

STRANDED TITANIUM CABLE - USEABLE FOR SHORT TETHERS SAME AS STEEL EXCEPT:

- SPACED COIL WIND MAY CAUSE YIELDING AT CROSSOVER POINTS RESULTING IN "KINKS" FOR SOME TETHER CONFIGURATIONS WITH HEAVIER SATELLITES
- HEAVIER THAN S-GLASS OR KEVLAR
- MAY HAVE DIFFICULTY LOCATING SUPPLIERS

CANDIDATE TETHER MATERIALS

BORON - NOT ACCEPTABLE

- HIGH MODULUS AND LARGE FILAMENT DIAMETER MEANS IMPRACTICAL MINIMUM SHEAVE DIAMETER
- LARGE FILAMENT DIAMETER MEANS FEW FILAMENTS THUS LARGE STRENGTH REDUCTION DUE TO FLAWS (HIGH PROBABILITY IN LONG TETHER)

GRAPHITE - NOT ACCEPTABLE

- DIFFICULT TO MANUFACTURE
- NO DIRECTLY APPLICABLE EXPERIENCE: REQUIRES DEVELOPMENT

F80-10

Ball

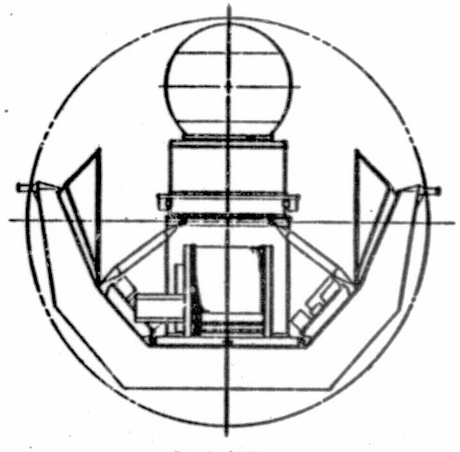
1400 – AUTONOMOUS–MOUNT (UNIQUE PALLET) – FEASIBILITY AND TRADEOFFS

THE BASELINE TSS DEPLOYER DESIGN WAS CONFIGURED AROUND THE SPACELAB PALLET. ALTERNATIVE INTERFACE STRUCTURES WERE EXAMINED WITH RESPECT TO SUCH FACTORS AS COST, STRUCTURAL STIFFNESS, SPACE OCCUPIED IN THE ORBITER BAY, STRUCTURAL COMPLEXITY, AND AVAILABILTY.

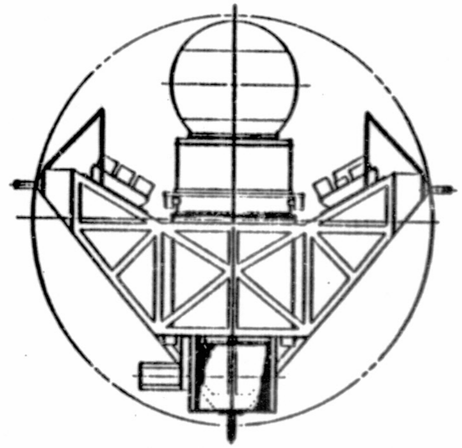
INFORMATION WAS OBTAINED FROM ROCKWELL INTERNATIONAL ON POSSIBLE ALTERNATIVES TO THE SPACELAB PALLET, SUCH AS MIGHT BE DEVELOPED BY ADAPTING EXISTING CARRIER DESIGNS.

A TSS-UNIQUE INTERFACE STRUCTURE (AIRBORNE SUPPORT EQUIPMENT) WAS ALSO CONFIGURED.

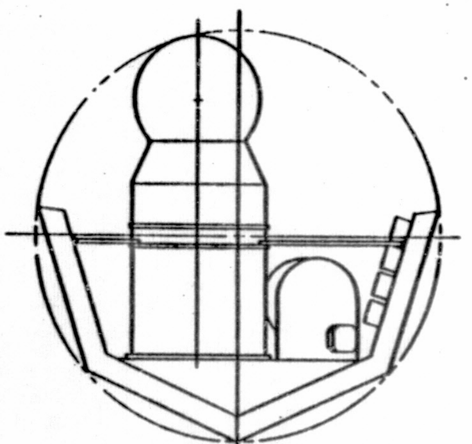
TSS AIRBORNE SUPPORT EQUIPMENT (ASE) CANDIDATE CONFIGURATIONS



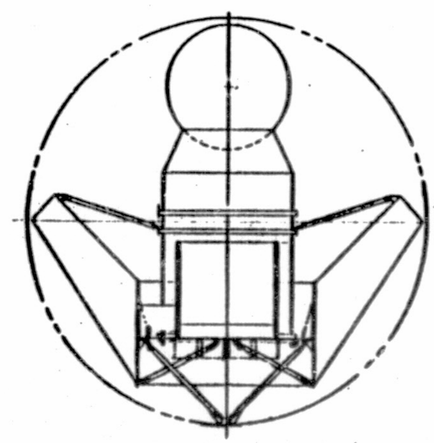
SPACELAB PALLET
BASELINE



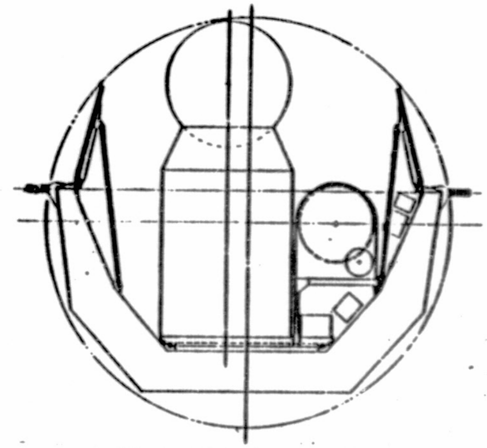
TSS – UNIQUE ASE
BASD



SMALL INSTR MTG SYS (SIMS)
RI

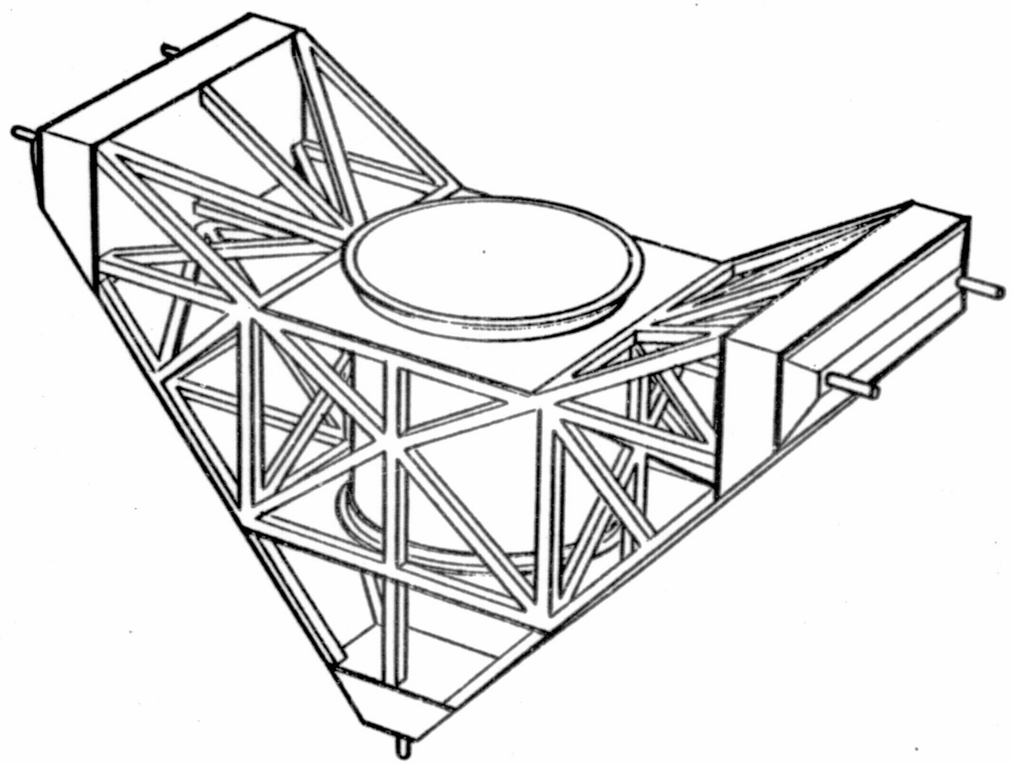


PBO CRADLE
RI

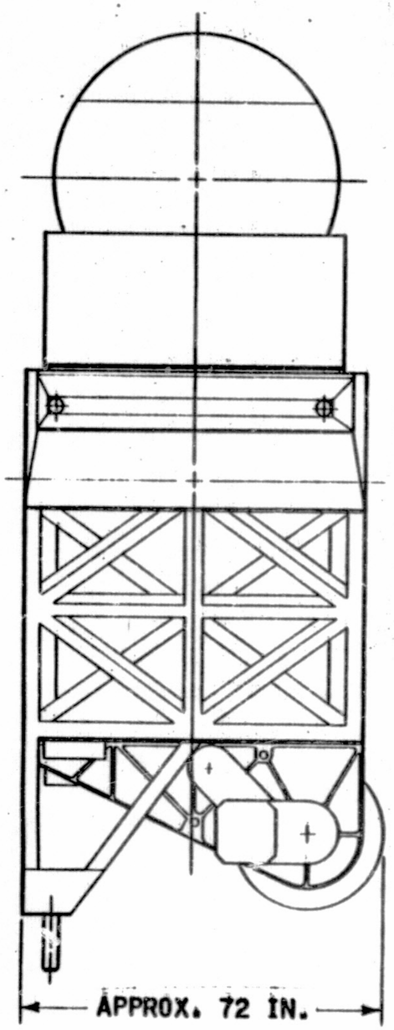


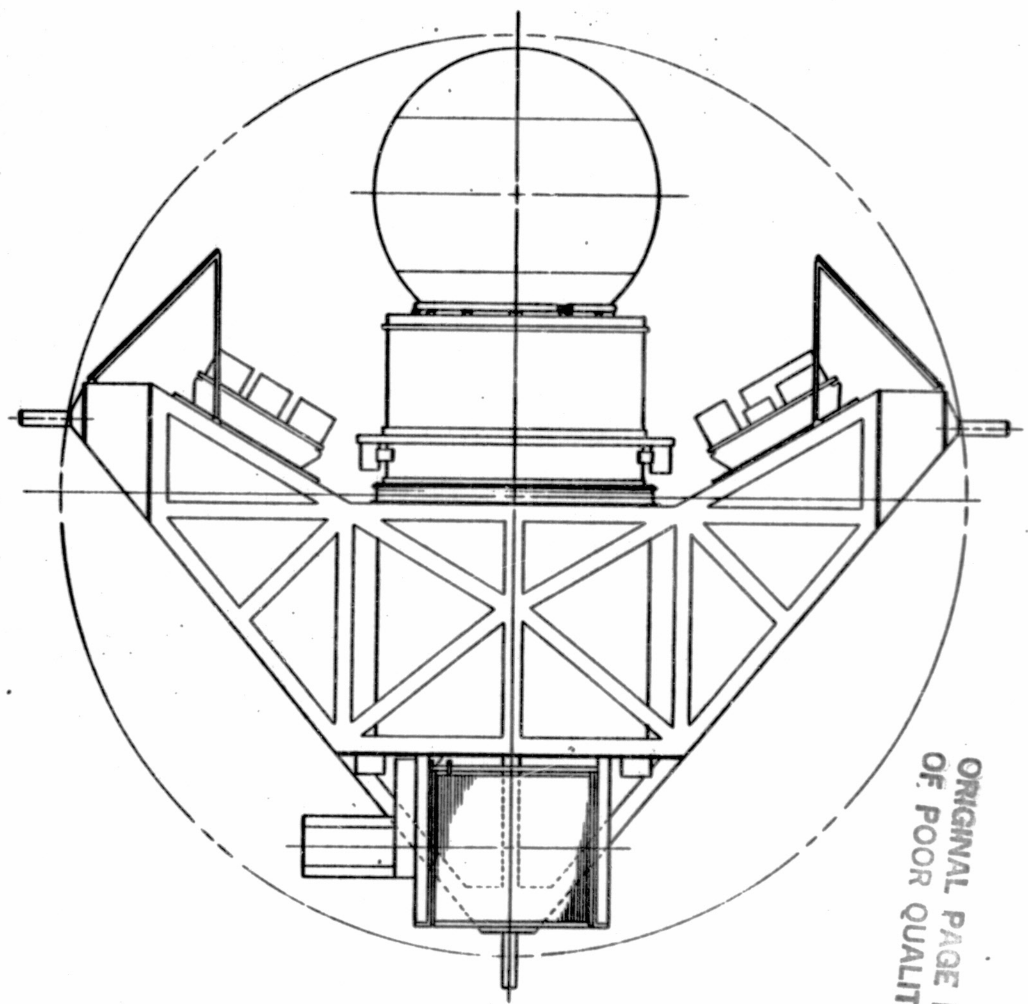
3 TRUNNION HALF PALLET
RI

TSS UNIQUE (AUTONOMOUS) MOUNT – BASD DESIGN



TSS UNIQUE (AUTONOMOUS) MOUNT AIRBORNE SUPPORT EQUIPMENT





TSS AIRBORNE SUPPORT EQUIPMENT (ASE)TRADE STUDY

	SPACELAB PALLET (BASELINE)	SIMS (ROCKWELL I.)	P80 CRADLE (ROCKWELL I.)	HALF-PALLET (ROCKWELL I.)	TSS-UNIQUE (BASD)
HARDWARE STATUS	QUALIFIED	NEW/MOD	MOD	MOD	NEW
"SERVICES" STATUS	EXISTING	NEW	NEW	EXISTING ?	NEW
ORBITER BAY LENGTH (APPROX. LAUNCH COST)	9.9 FT ($7.2 M)	5.6 FT ($4.1 M)	8.4 FT ($6.1 M)	5.6 FT ($4.1 M)	6.5 FT ($4.7 M)
TETHER ROUTING	ACCEPTABLE	ACCEPTABLE	ACCEPTABLE	VERY POOR	BEST
STRUCTURAL RIGIDITY	POOR	VERY POOR	GOOD	POOR	BEST
LOAD CONSTRAINTS (HARD-POINT LIMITS)	POOR	UNKNOWN	UNKNOWN	VERY POOR	BEST
COMPONENT ARRANGEMENT	GOOD	ACCEPTABLE	ACCEPTABLE	VERY POOR	GOOD
COMPONENT ACCESSIBILITY	BEST	POOR	ACCEPTABLE	ACCEPTABLE	ACCEPTABLE
MASS-PROPERTIES CONSTRAINTS	ACCEPTABLE	UNKNOWN	UNKNOWN	POOR (C.G. CONTROL)	BEST
ORBITER ENVELOPE CLEARANCE	GOOD	POOR	GOOD	POOR	GOOD

SPACELAB PALLET TRADEOFF - CONCLUSION

THE LOWER LAUNCH COST, GREATER STRUCTURAL RIGIDITY, AND BETTER TETHER ROUTING OF THE NEW TSS-UNIQUE ASE, MORE THAN OFFSET THE COSTS OF DESIGNING, FABRICATING, AND QUALIFYING THIS NEW STRUCTURE, AND OF PROVIDING THE REQUIRED ORBITER INTERFACES AND TSS "SERVICES".

F80-10

1500 - COST OPTIMIZATION

- SATELLITE - COST EFFECTS OF REDUCED CAPABILITY
- DEPLOYER - REDUCED REELING RATES

DURING THE STUDY EXTENSION, AS A RESULT OF SYSTEM STUDIES AND EXPERIMENT REQUIREMENTS DEFINITION, ADDITIONAL GUIDELINES WERE IMPOSED ON THE "BASELINE" PROGRAM FOR THE PURPOSE OF COST STUDIES AND THE ACCOMPANYING SYSTEMS ANALYSIS. THE ORIGINAL REQUIREMENTS, WHERE MORE STRINGENT OR GENERAL, WERE RETAINED AS PROGRAM GOALS.

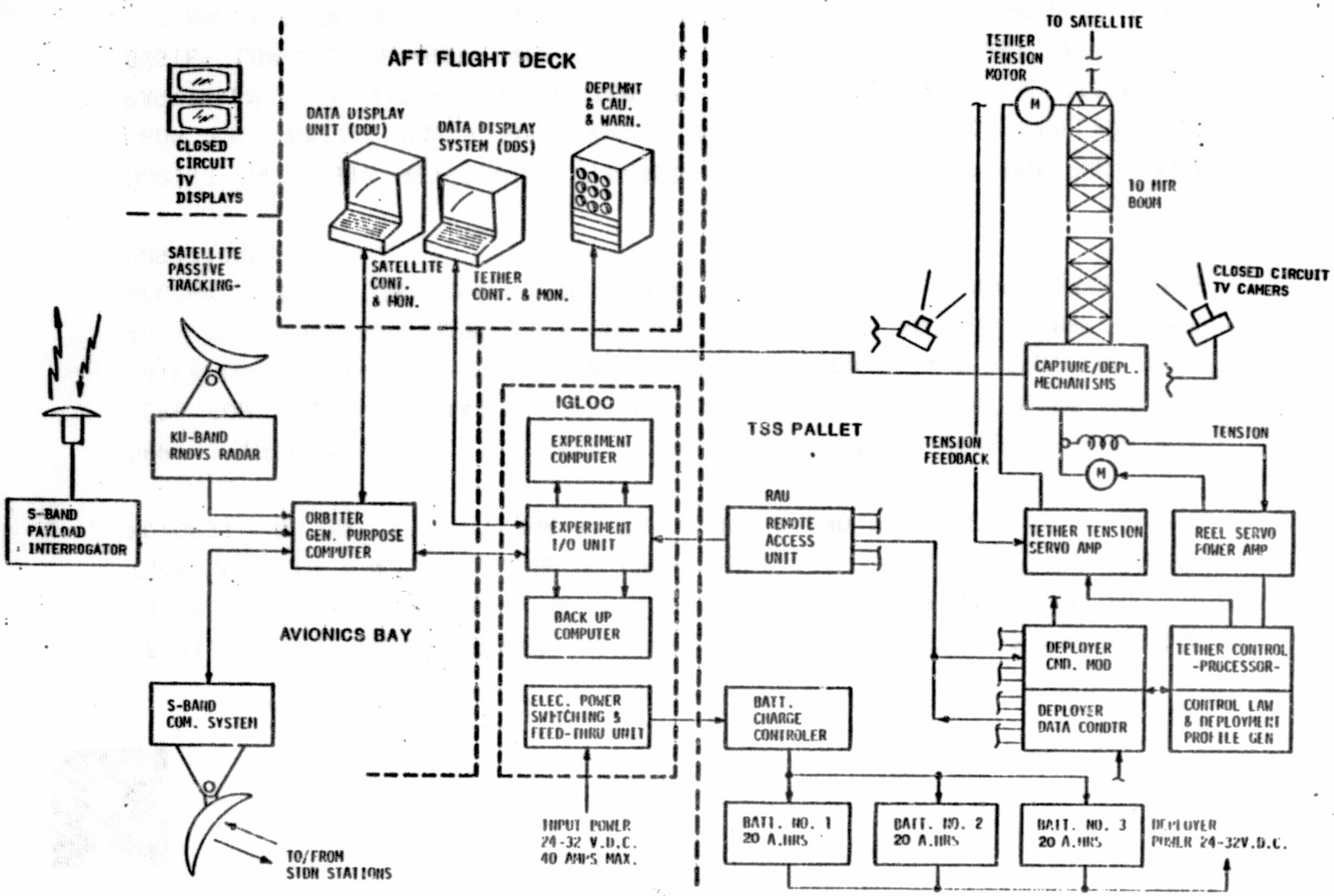
SYSTEM COST STUDIES WERE DIRECTED AT TWO PRINCIPAL AREAS:

- CAPABILITY TRADEOFFS RELATED TO REDUCTION IN COMPLEXITY OF THE SATELLITE,
- REDUCTION OF DEPLOYER CAPABILITY RELATIVE TO REELING RATES.

REVISIONS TO COST STUDY GUIDELINES

	BASELINE REQUIREMENTS INITIAL	REVISED
MINIMUM SATELLITE ALTITUDE	120 KM	130 KM
SATELLITE ATTITUDE STABILIZATION	NOT SPECIFIED	TO BE DEMONSTRATED
SATELLITE ATTITUDE STABILIZATION METHOD	------	AERODYNAMIC
TETHER MATERIAL – VERIFICATION FLIGHT	NOT SPECIFIED	NON-CONDUCTING

ORBITER-MOUNTED SUPPORT EQUIPMENT

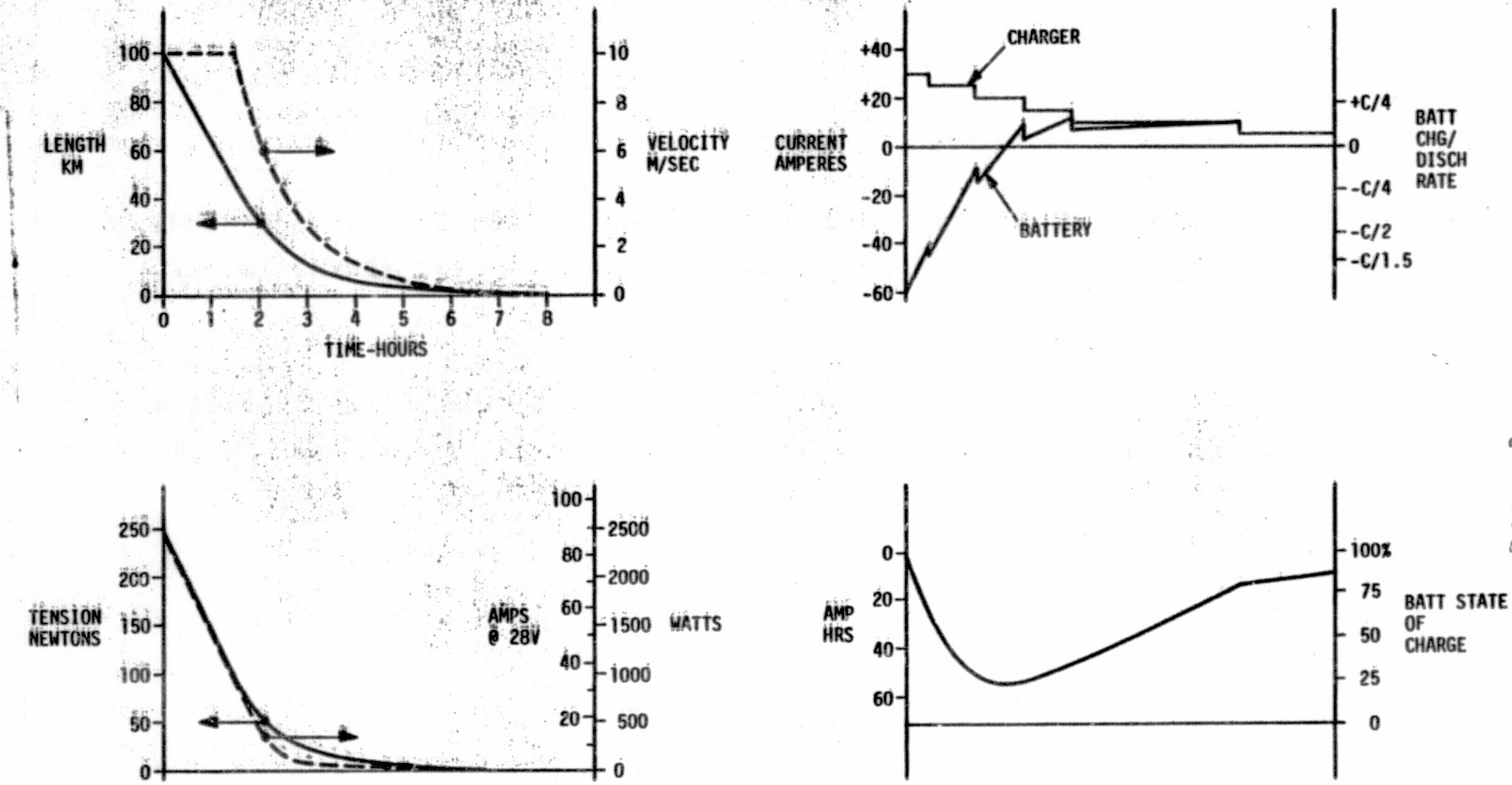


RETRIEVAL AND PAYOUT DURATIONS ARE DEPENDENT TO SOME EXTENT ON THE MAXIMUM REELING CAPABILITY OF THE DEPLOYER. THE REELING RATE USED IN TURN AFFECTS THE REQUIREMENTS FOR ELECTRICAL POWER, THE SIZING OF MOTORS, AND THE CAPACITY FOR ENERGY STORAGE AND DISSIPATION.

DURING INITIAL STUDIES REELING RATES AS HIGH AS 50 METERS PER SECOND WERE CONSIDERED DESIRABLE. IT WAS LATER CONCLUDED THAT HIGH REELING RATES COULD ONLY BE USED DURING A SMALL PORTION OF THE RETRIEVAL TIME AND, THEREFORE THE CAPABILITY COULD BE REDUCED TO ABOUT TEN METERS PER SECOND WITHOUT SERIOUSLY INCREASING RETRIEVAL AND DEPLOYMENT TIME DURATIONS.

DURING SATELLITE RETRIEVAL, ELECTRICAL ENERGY IS SUPPLIED PARTIALLY FROM THE ORBITER POWER BUS THROUGH A BATTERY CHARGE CONTROLLER, AND PARTIALLY FROM BATTERIES LOCATED ON THE TSS PALLET. THE SIZING OF SYSTEM COMPONENTS MUST TAKE INTO CONSIDERATION THE CAPABILITY OF THE STORAGE BATTERIES WITH REGARD TO DISCHARGE RATES, DEPTH OF DISCHARGE, AND THE DEMANDS ON THE ORBITER POWER SYSTEM.

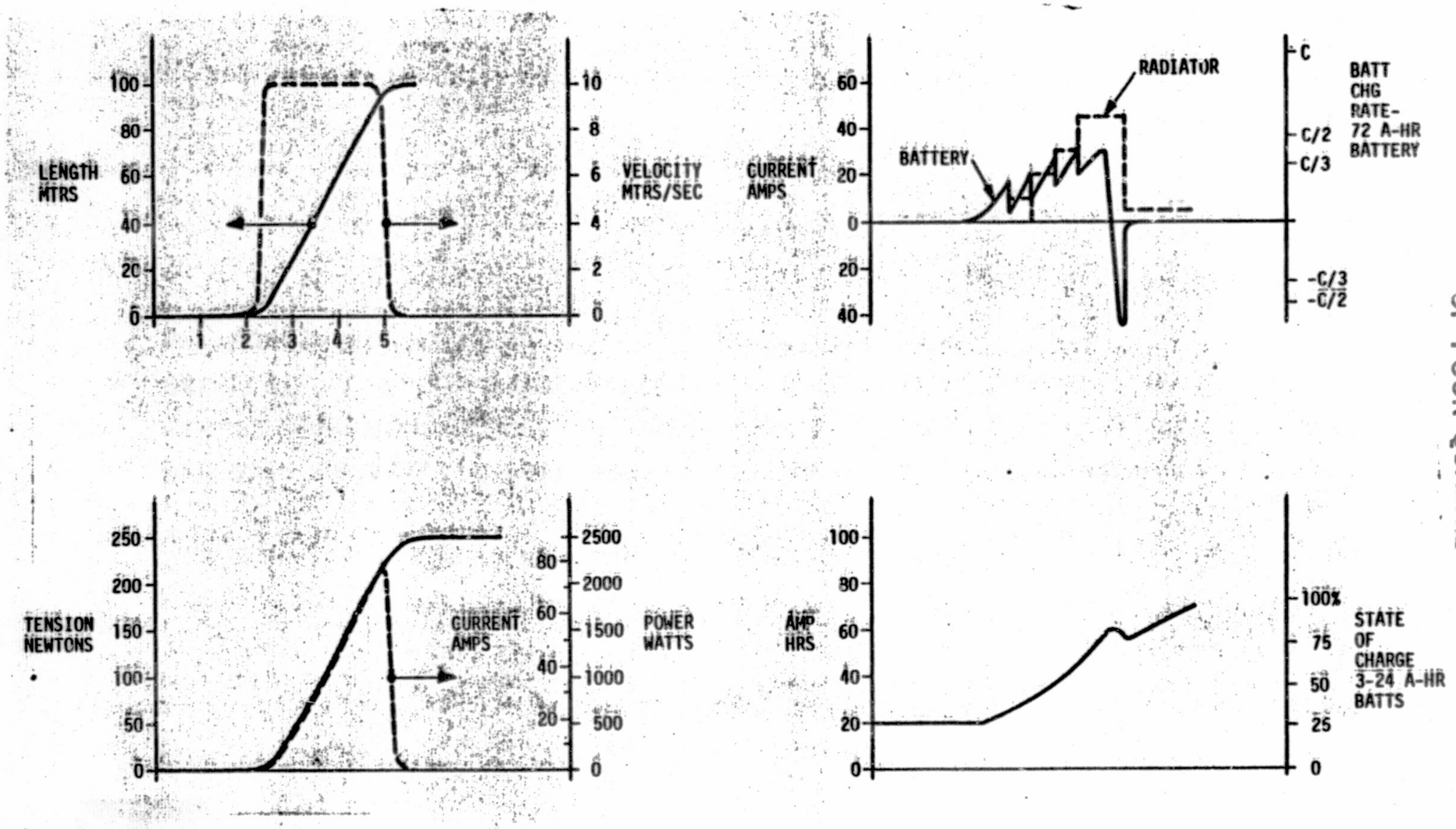
DEPLOYER ELECTRICAL POWER PROFILES - RETRIEVAL (500Kg SAT. + 150Kg TETHER)



DURING DEPLOYMENT, EXCESS ENERGY IS PARTIALLY STORED IN THE DEPLOYER BATTERIES AND PARTIALLY DISSIPATED AS HEAT FROM THE AUXILIARY RADIATORS.

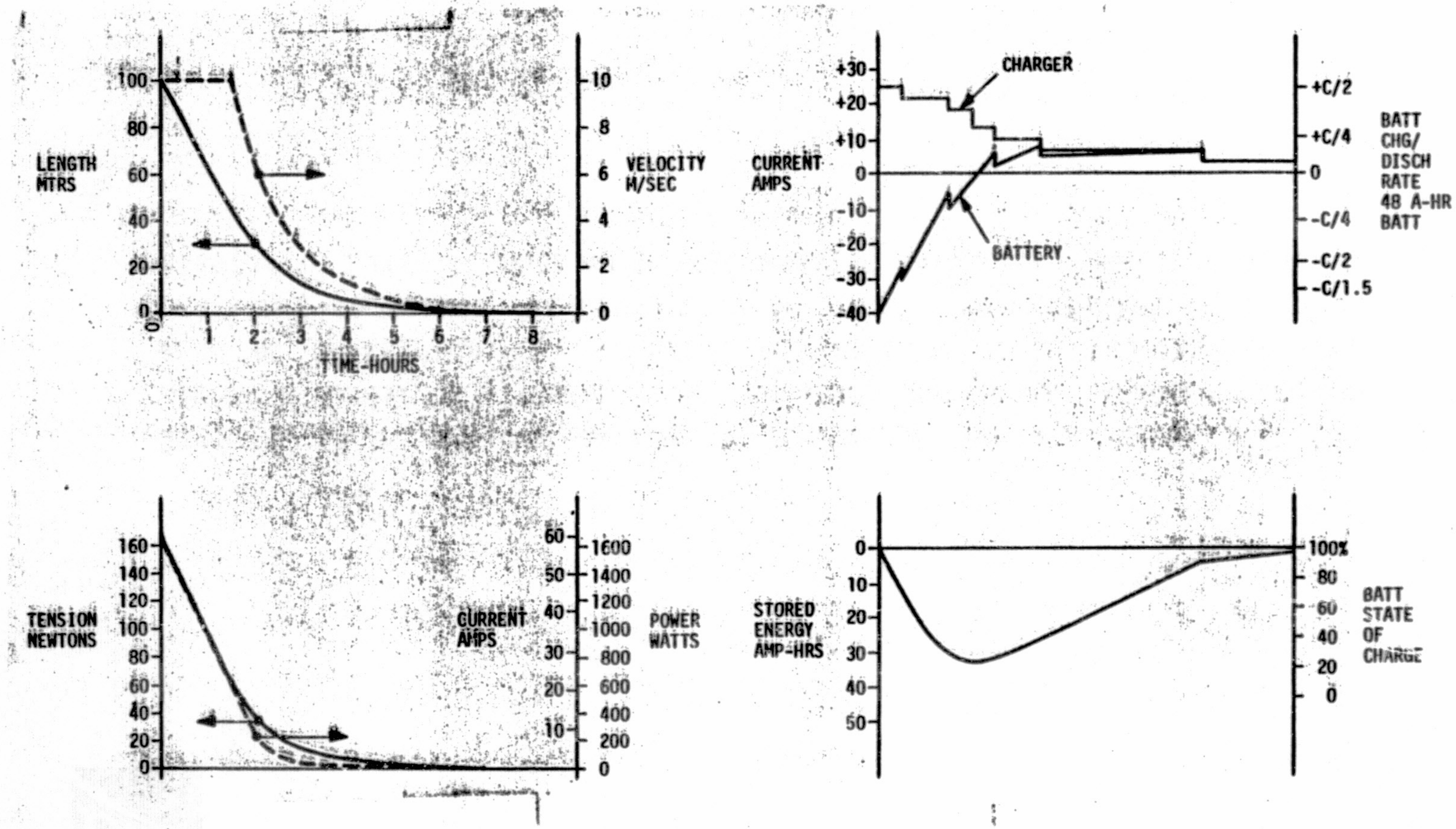
BATTERY CHARGE RATES, STORAGE CAPACITY AND RADIATOR SIZES AND TEMPERATURES ARE AFFECTED BY THE SELECTION OF THE MAXIMUM DEPLOYMENT RATES.

DEPLOYMENT PROFILES–(500Kg SAT. + 150Kg TETHER)



DEPLOYER CAPABILITY WITH REGARD TO STORAGE AND POWER HANDLING CAPACITY MAY BE SOMEWHAT REDUCED FOR SMALLER SATELLITES. FOR A 300 KILOGRAM SATELLITE A 48 AMP/HOUR BATTERY IS SUFFICIENT, COMPARED TO ONE OF 72 AMP/HOURS REQUIRED FOR A 500 KILOGRAM SATELLITE.

RETRIEVAL OF 300Kg SATELLITE-(100Kg TETHER)



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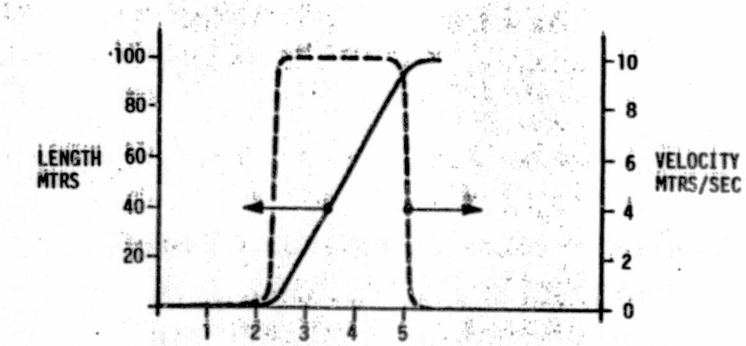
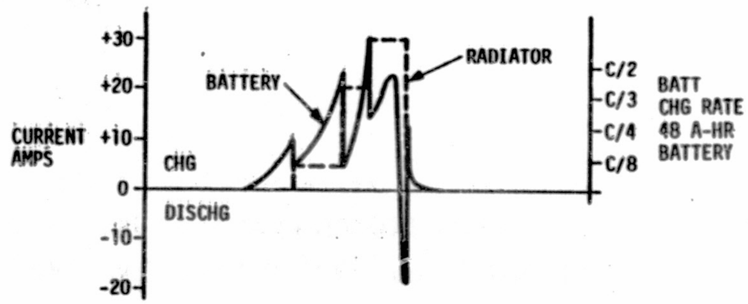
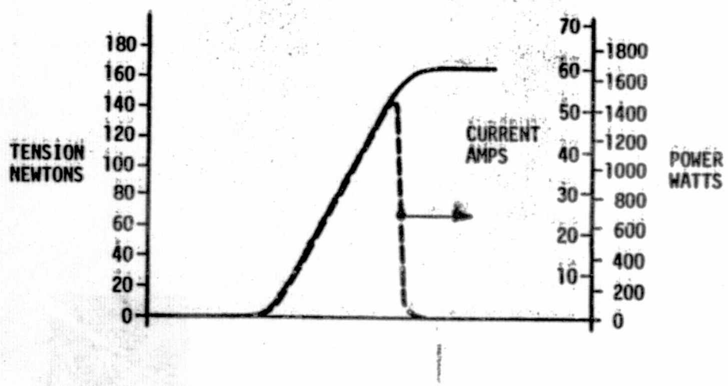
OF POOR QUALITY

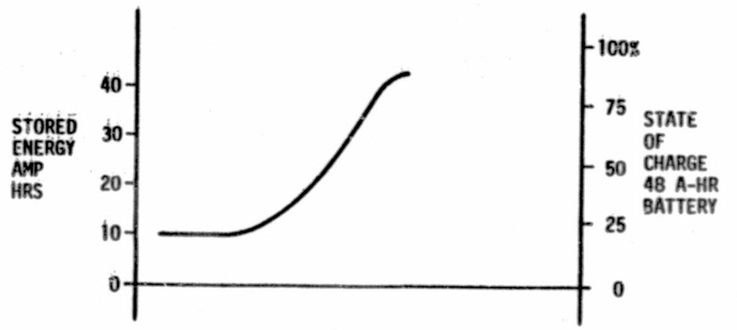
SIMILARLY A 48 AMP/HOUR BATTERY IS SUFFICIENT FOR DEPLOYMENT OF A 300 KILOGRAM SATELLITE. MOTOR SIZE AND POWER AMPLIFIER CAPABILITY COULD ALSO BE CORRESPONDINGLY REDUCED, ALTHOUGH IT WOULD PROBABLY NOT BE DESIRABLE TO REDUCE THE CAPABILITY OF THESE COMPONENTS FOR AN INITIAL MISSION IF LATER FLIGHTS WITH MORE MASSIVE SATELLITES WERE PLANNED.

DEPLOYMENT OF 300Kg SATELLITE–(100Kg TETHER)









SATELLITE EQUIPMENT COMPLEMENTS DECREASE CORRESPONDING TO THE FUNCTIONAL CAPABILITY OF THE SATELLITE, AND THESE REDUCTIONS CONSTITUTE THE GREATEST POTENTIAL SAVINGS TO BE REALIZED IF SUCH AN ALTERNATIVE WERE PURSUED. FOR INSTANCE, THE PASSIVE SATELLITE, OR "DUMB-BALL" WOULD CONTAIN NO ACTIVE INSTRUMENTATION OR ELECTRICAL EQUIPMENT.

Ball

EQUIPMENT COMPLEMENT FOR REDUCED CAPABILITY COST TETHERED SATELLITE CONFIGURATION

	1 PASSIVE SATELLITE	2 RECORDED DATA	3 REAL TIME DATA	4 COMMAND & POSITION	5 LOW ALT. EXPLORATORY	6 BASELINE
SPHERICAL STRUCT. W/ DROGUE SOCKET	X	X	X	X	X	X
"PASSIVE" TEMP SENSORS	X					
ELECTR. TEMP SENSORS		X	X	X	X	X
ANALOG RECORDER & TIMER		X				
BATTERIES		X	X	X	X	X
TELEMETRY SYSTEM & ANTENNA			X	X	X	X
COMMAND SYSTEM & ANTENNA				X	X	X
Ku-BAND BEACON TRANS. & ANTENNA				X	X	X
ATTITUDE CONTROL VANE					X	X
THERMAL RADIATOR				X	X	X
PHASE CHG. SHELF				X	X	X
MAGNETOMETER - 3 AXIS (ATT. DETERMINATION)					X	X
ION GAUGE						X
TETHER TENSION INST.						X

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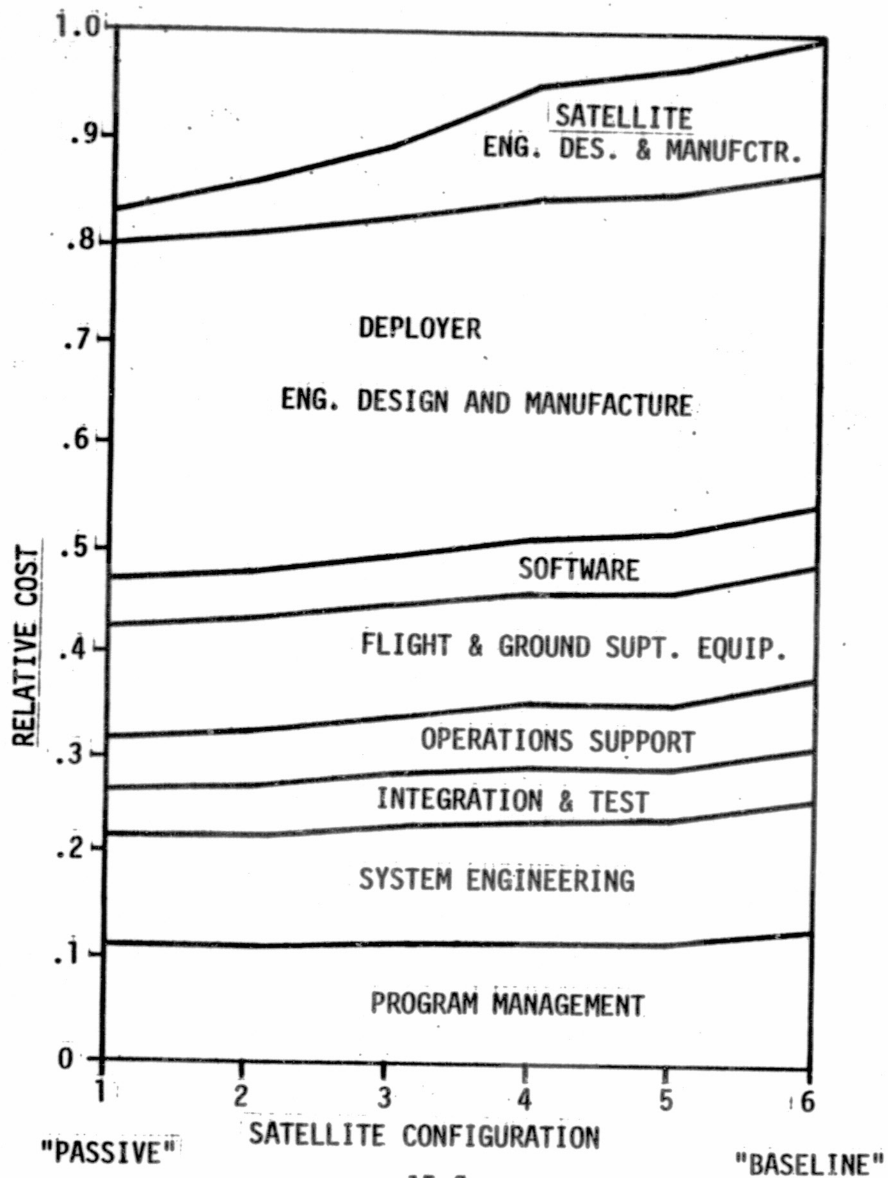
ALTHOUGH THE VERIFICATION CAPABILITY AND THE POSSIBLITY OF COLLECTING SCIENTIFIC DATA DECREASE MARKEDLY AS THE DATA RETRIEVAL CAPABILITY OF THE SATELLITE IS REDUCED, NEARLY ALL OF THE DEPLOYER AND MANY OF THE MISSION OPERATIONAL FUNCTIONS COULD BE VERIFIED USING A SIMPLER SATELLITE.

CAPABILITY OF VARIOUS SATELLITE VERSIONS

	1 PASSIVE SATELLITE	2 RECORDED DATA	3 REAL TIME DATA	4 COMMD. & POSIT. DET.	5 LOW ALT. EXPLORATORY	6 BASELINE CONFIG.
SATELLITE ALTITUDE MINIMUM - KM	135	135	135	130	120	120
TETHER LENGTH-MAX-KM-(ORBITER AT 220)	85	85	85	90	100	100
STRUCTURAL TEMP MEASUREMENT						
AFTER-THE-FACT-APPROX. EXCURSION	X					
AFTER-THE-FACT-HISTORY		X				
REAL TIME			X	X	X	X
SATELLITE POSITION MEAS.-MAX RANGE (KM)	22	22	22	100+	100+	100+
SATELLITE ATTITUDE CONTROL						
ARBITRARY AZIMUTH ATTITUDE	X	X	X	X		
APPROX. CONTROL RE. VEL VECTOR ($\pm$ 10°)					X	X
SATELLITE ATTITUDE DETERMINATION						
INFERRED FROM TEMP. DATA					X	
3-AXIS DETERMINATION TO $\pm$ 3°						X
EXPERIMENT ACCOMODATION CAPABILITY						
PASSIVE, SELF CONTAINED EXP. ONLY	X	X	X	X	X	X
DATA - 1KBS + HSKPG.			X	X	X	X
COMMANDS - 32 DISCRETE - 8 SERIAL				X	X	X
ELECTRICAL POWER (ENERGY W-HRS)	—	—	620	600	600	575
CONTROLLED ATTITUDE					X	X

RELATIVE PROGRAM COSTS- VARIOUS SATELLITE CONFIGURATIONS



COST OPTIMIZATION STUDY RESULTS

- <u>SATELLITE OF REDUCED CAPABILITY</u>. REDUCING THE EXPERIMENT ACCOMMODATION AND REAL-TIME "VERIFICATION" CAPABILITY RESULTS IN ONLY A MODEST REDUCTION IN TOTAL PROGRAM COSTS, SINCE THE COST OF THE BASELINE SATELLITE IS ONLY ABOUT 30 PERCENT OF THAT OF THE TOTAL PROGRAM.

- <u>DEPLOYER</u>. REELING RATES CAN BE REDUCED TO ABOUT 10 MTR/SEC WITHOUT SERIOUSLY AFFECTING TOTAL DEPLOYMENT AND RETRIEVAL TIME, SINCE HIGH REELING RATES WOULD BE USED FOR ONLY PERIODS OF SHORT DURATION. THIS ENABLES USE OF SMALLER MOTORS, AMPLIFIERS, AND POWER CONVERTERS.

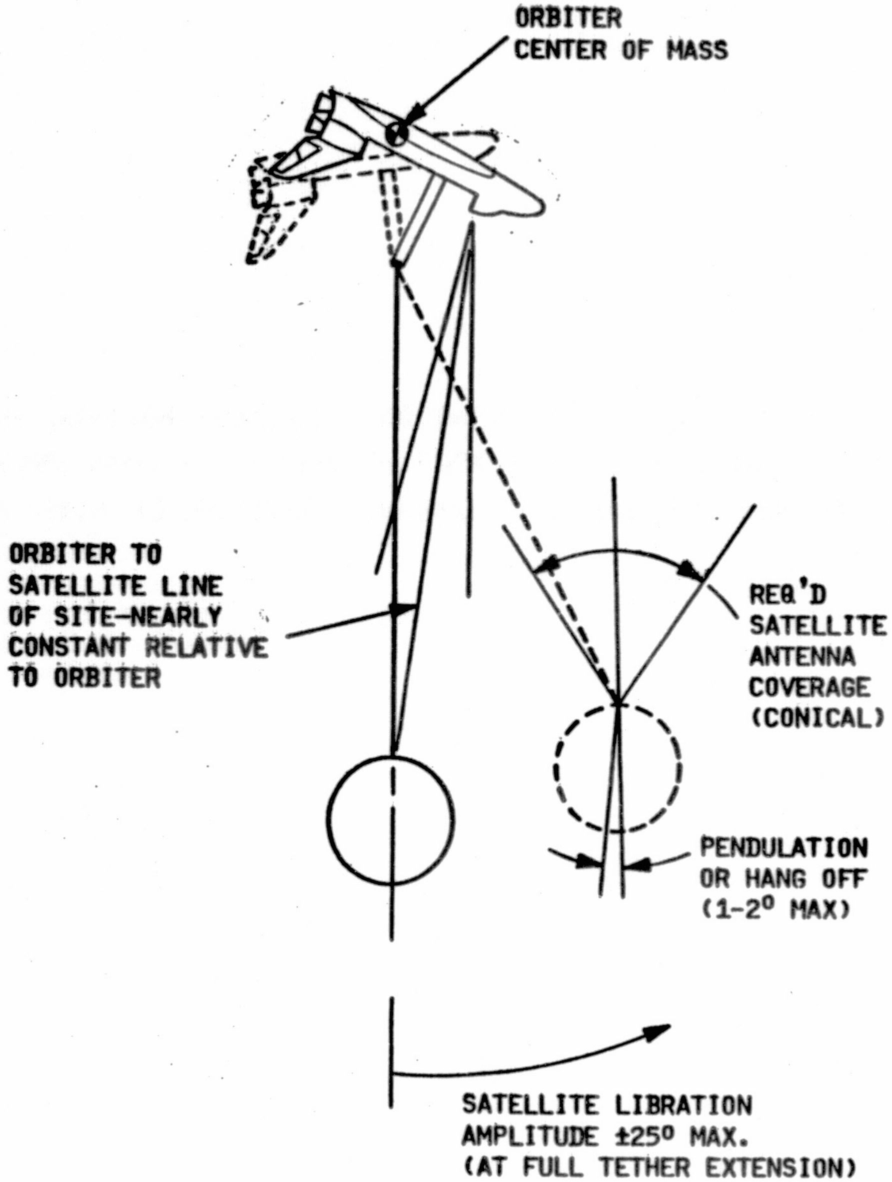
1600 - SPECIAL STUDIES

- ORBITER - SATELLITE COMMUNICATIONS - INCREASED DATA RATE
- POSITION DETERMINATION - TRADEOFFS AND SELECTION

SUBSTANTIAL COST SAVINGS CAN BE REALIZED BY USING THE ORBITER PAYLOAD INTERROGATOR AND ITS ASSOCIATED ANTENNA FOR COMMUNICATION WITH THE SATELLITE AS COMPARED TO THE USE OF SPECIAL PURPOSE COMMUNICATIONS EQUIPMENT PECULIAR TO THE TETHERED SATELLITE SYSTEM.

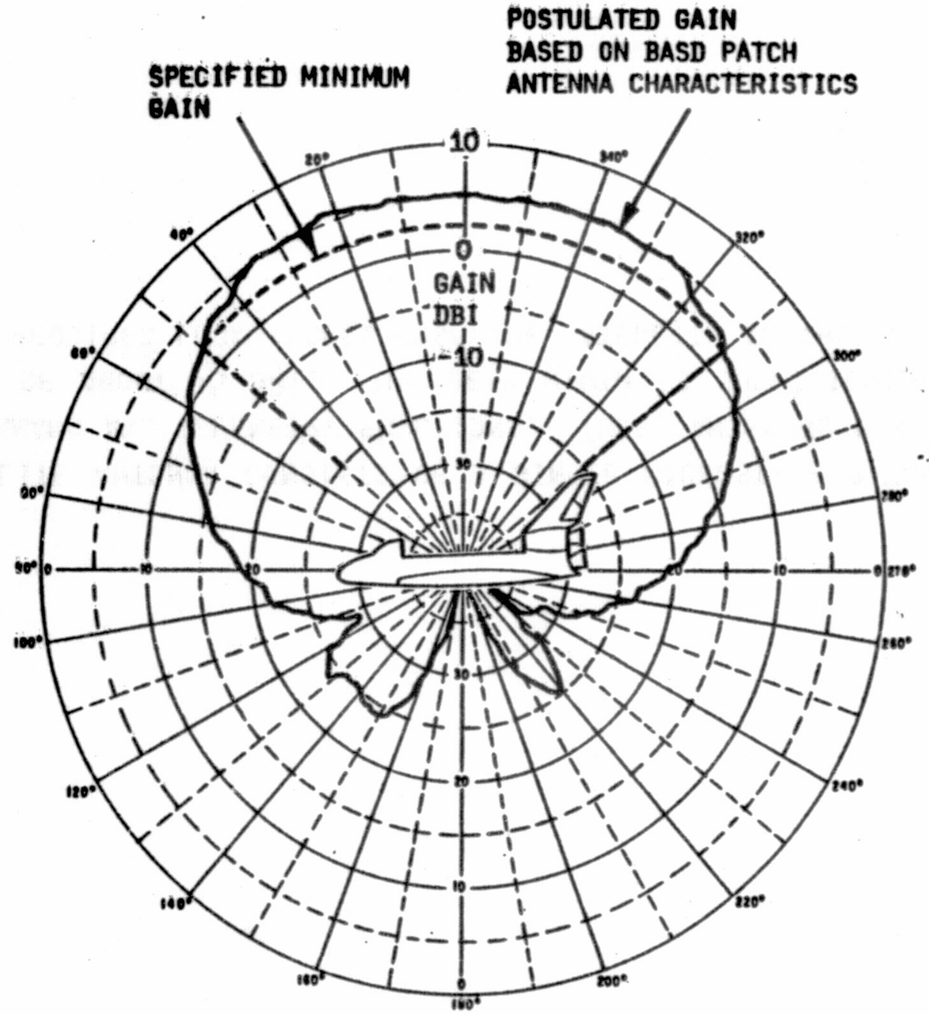
THE ORBITER PAYLOAD INTERROGATOR ANTENNA PATTERN IS REASONABLY COMPATIBLE WITH THE TSS REQUIREMENTS, FOR DATA RATES UP TO 8 KILOBITS PER SECOND, USING A SINGLE SATELLITE ANTENNA AND MODERATE SATELLITE TRANSMITTER RF POWER LEVELS. THE ORBITER ANTENNA PATTERN IS SUFFICIENTLY BROAD TO ACCOMMODATE THE TETHERED SATELLITE SYSTEM WITH THE PALLET MOUNTED IN ANY LOCATION IN THE PAYLOAD BAY. THE LOOK ANGLE TO THE SATELLITE FROM THE ORBITER REMAINS RELATIVELY CONSTANT IN SPITE OF LIBRATION OF THE SATELLITE BENEATH THE ORBITER OR THE SELECTION OF PALLET MOUNTING POSITIONS.

ANTENNA PITCH LOOK-ANGLE GEOMETRY



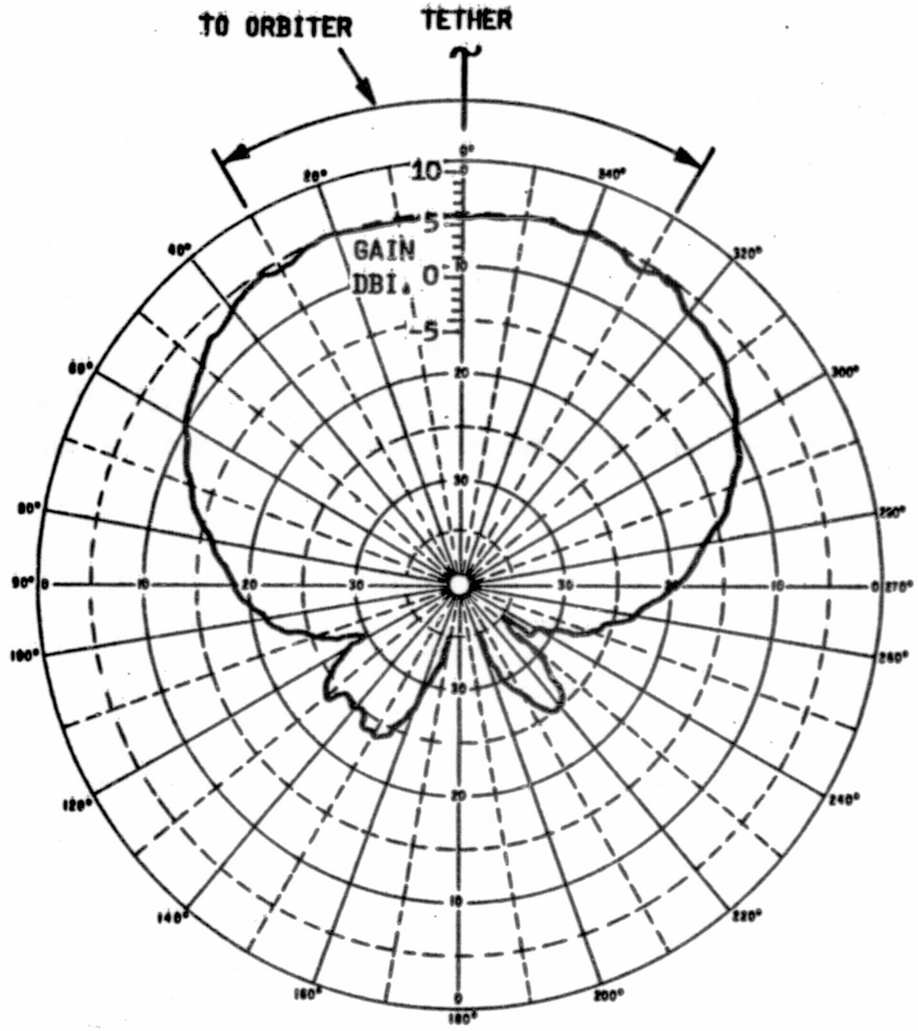
ADDITIONAL GAIN IS PROBABLY INHERENT IN THE ORBITER PAYLOAD INTERROGATOR ANTENNA OVER THE RANGE OF LOOK ANGLES REQUIRED ABOVE THAT SPECIFIED IN THE ORBITER INTERFACE DOCUMENTATION.

ORBITER PAYLOAD INTERROGATOR ANTENNA PATTERN



THE SATELLITE ANTENNA CONSISTS OF A SINGLE MICROSTRIP PATCH FOR EACH OF THE COMMAND AND TELEMETRY FUNCTIONS. THESE ANTENNAS EXHIBIT AN ON-AXIS GAIN OF ABOUT +5 DBI. THE BEAM WIDTH IS SUFFICIENTLY BROAD TO COVER ALL REQUIRED LOOK ANGLES FROM THE SATELLITE TO THE ORBITER.

SATELLITE ANTENNA PATTERN



THE COMMAND LINK MARGIN, CALCULATED USING THE LINK PARAMETERS SPECIFIED IN THE ORBITER INTERFACE CONTROL DOCUMENTATION (ICD) IS 11.1 dB

Circuit Margin Calculation Summary,
Tethered Satellite S-Bank Link

2 Kbps Command Channel

	PARAMETER	VALUE	SOURCE
1.	SSO Transmit power, dBW	7.0	5 W
2.	SSO transmit circuit loss, dB	-9.8	Rockwell estimate based upon latest cable lengths, etc.
3.	SSO transmit antenna gain, dB	2.5	Omni, specified over 18% of coverage each sphere
4.	SSO EIRP, dBW	-0.3	Sum 1 through 3
5.	Space loss, dB	-139.0	f=2115.6 MHz, R=100 Km
6.	Payload receive antenna gain, dB	+5	Measured gain of patch antenna over $\pm$ 50° cone
7.	Payload receive circuit loss, dB	-2.0	Estimate
8.	Total received power, dBW	-136.3	Sum 4 through 7
9.	Payload system noise temperature	33.6	2303.5 K (ref. to receiver input T_a=290 K, L=-2.0 dB, T_r-2613.6 K)
10.	Boltzmann's constant, dB (W/K/Hz)	-228.6	1.38×10^{-23} W/K/Hz
11.	Payload noise spectral density, dB (W/Hz)	-195.0	Sum 9 and 10
12.	NASA Payload G/T, dB/K	-35.6	7 minus 9
13.	Total received power/noise spectral density (P_{rec}/N_o), dBHz	58.7	8 minus 11 or 4 plus 5 minus 10 plus 12
14.	Modulation loss (LM_s), dB	-3.5	β_s-1.1 rad.
15.	Subcarrier signal-to-noise spectral density (P_s/nsd), dBHz	55.2	13 plus 14
16.	Bit rate bandwidth, dBHz	33.0	2 kbps
17.	SNR in bit rate bandwidth (E_b/nsd), dB	22.2	15 minus 16
18.	Theoretical required E_b/nsd, dB	9.6	For 10^{-5} BEP
19.	Bit sync degradation, dB	-1.5	Estimate
20.	Required E_b/nsd, dB	11.1	18 minus 19
21.	Required P_{rec}/N_o, dBHz	36.8	20 plus 17 minus 14
22.	Circuit margin, dB	11.1	17 minus 20 or 13 minus 21

16-4

F80-10

For a Bit Error Rate (BER) of 1 in 10^5, and a data rate of 8 Kbps., the telemetry data link margin is +3.5 dB. An additional margin of up to about 2 dB is probably inherent in the link due to the gain of the Orbiter payload interrogator antenna throughout the angular coverage required.

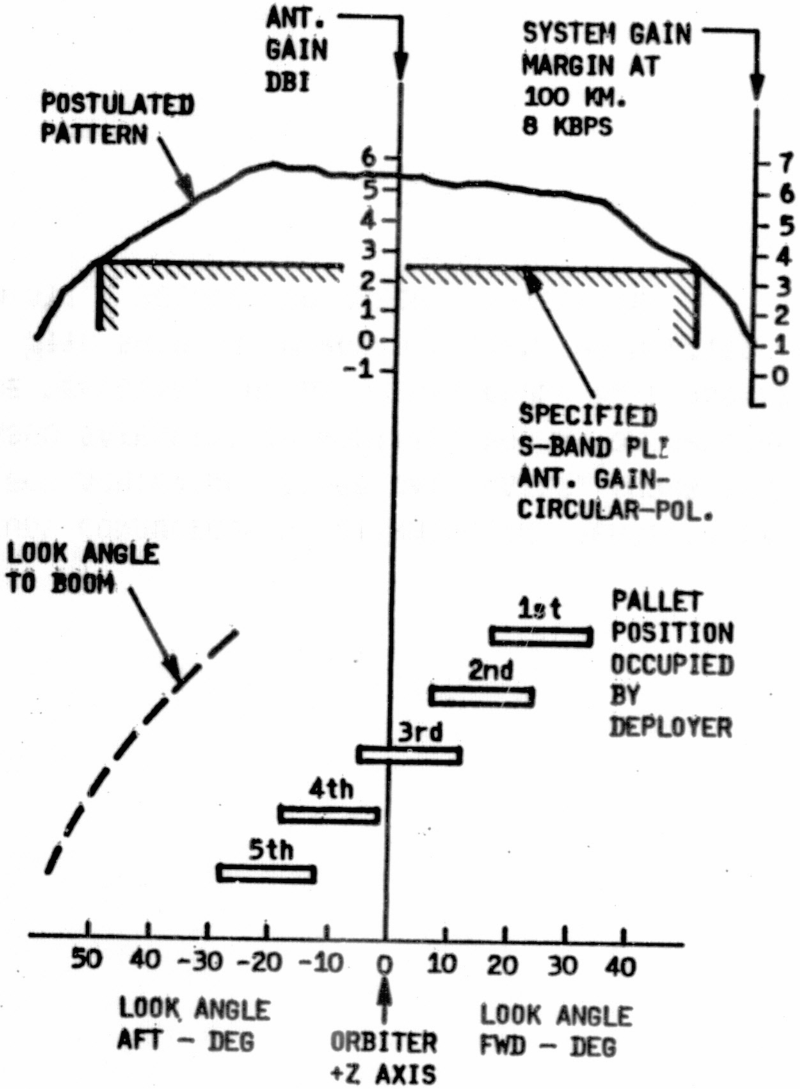
Circuit Margin Calculation Summary, Tethered Satellite S-Band Link

8 Kbps Telemetry Channel

	PARAMETER	VALUE	SOURCE
1.	Payload transmit power, dB	4.0	2.5W
2.	Payload transmit circuit loss, dB	-1.0	.15db/ft (6 ft)
3.	Payload transmit antenna gain, dB	+5	Measured gain of patch antenna over $\pm$ 30° cone
4.	Payload EIRP, dBW	8	Sum 1 through 3
5.	Space loss, Db	-139.7	f=2297.5 MHz, R=100 Km
6.	SSO antenna gain, dB	2.5	Omni, specified over 18% of coverage sphere ($\pm$ 50 cone)
7.	SSO receive circuit loss, dB	-9.8	Rockwell estimate based upon latest cable lengths, etc.
8.	Total received power, dBW	-139	Sum 4 through 7
9.	SSO system noise temperature, dBK	32.5	1800 K ref. to Payload interrogator
10.	Boltzmann's constant, dB (W/K/Hz)	-228.6	1.38×10^{-23} W/K/Hz
11.	SSO noise spectral density, dB (W/Hz)	-196.1	Sum 9 and 10
12.	SSO G/T, dB/K	-39.8	6 plus 7 minus 9
13.	Total received power/noise spectral density (P_{rec}/N_o), dBHz	57.1	8 minus 11 or 4 plus 5 minus 10 plus 12
14.	Modulation loss (LM_s), dB	-3.5	β_s -1.1 rad.
15.	Subcarrier signal-to-noise spectral density (P_s/nsd), dBHz	53.6	13 plus 14
16.	Bit rate bandwidth, dBHz	39	8 kbps
17.	SNR in bit rate bandwidth (E_b/nsd), dB	14.6	15 minus 16
18.	Theoretical required E_b/nsd, dB	9.6	For 10^{-5} BEP
19.	Bit sync degradation, dB	-1.5	Estimate
20.	Required E_b/nsd, dB	11.1	18 minus 19
21.	Required P_{rec}/N_o, dBHz	53.6	20 plus 16 minus 14
22.	Circuit Margin, dB	3.5	17 minus 20 or 13 plus 21

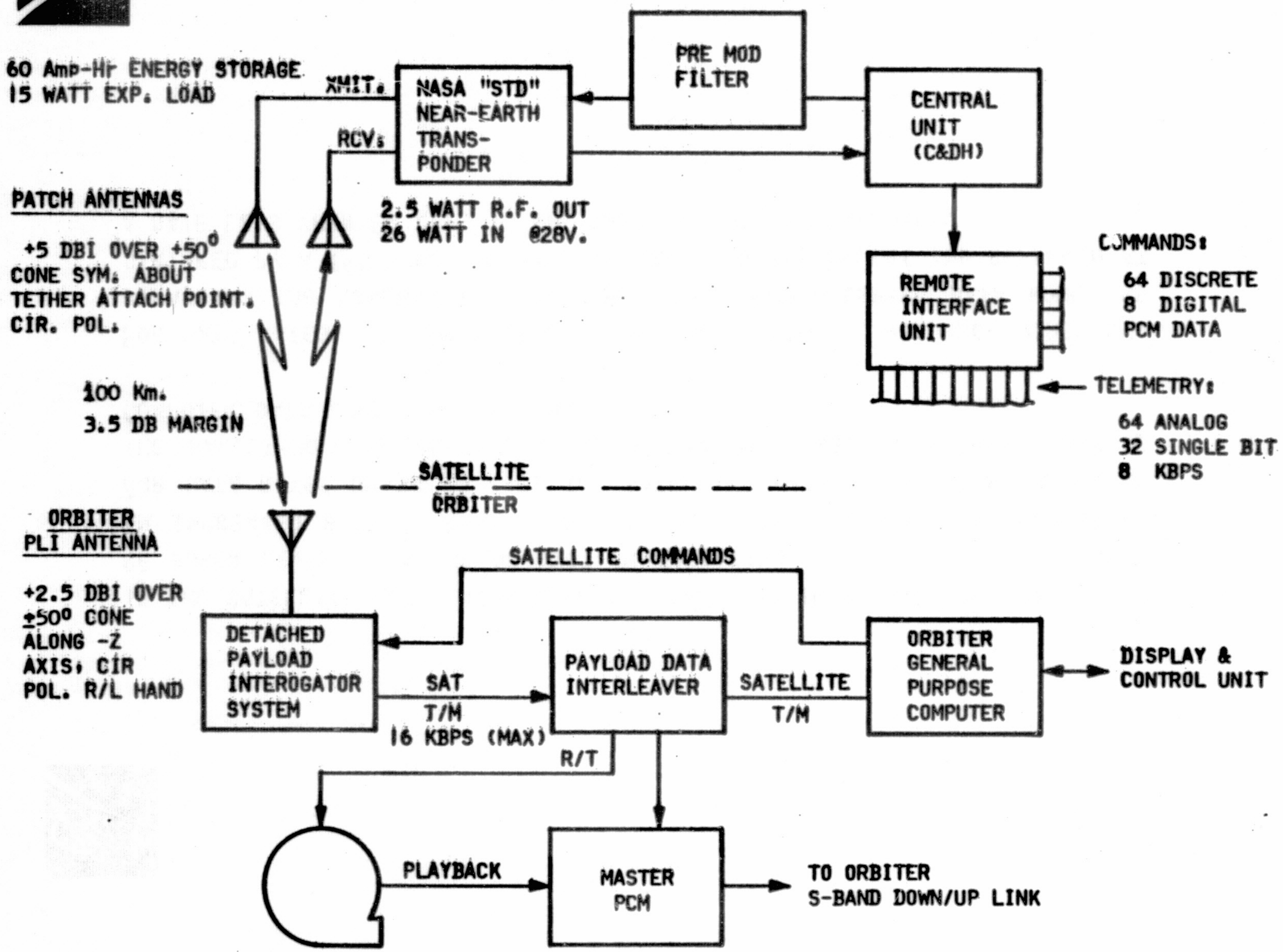
THE DATA LINK MARGIN IS AT LEAST 3.5 dB FOR ANY PALLET MOUNTING POSITION, THE GREATEST MARGIN IS AVAILABLE FOR THE CENTRAL PALLET POSITIONS NUMBERS 2, 3 AND 4.

ORBITER PLI ANTENNA LOOK ANGLES AND RESULTING SYSTEM MARGINS



A TRADEOFF STUDY CONDUCTED TO DETERMINE THE FEASIBILITY AND EQUIPMENT REQUIREMENTS FOR ACHIEVING HIGHER DATA RATES, SHOWS THAT THROUGH THE USE OF INCREASED SATELLITE TRANSMITTER POWER, OR SPECIAL EQUIPMENT LOCATED ON THE DEPLOYER, THE DATA RATE COULD BE REASONABLY INCREASED TO 256 KBPS. WITH SUCH AN IMPROVED SYSTEM THE ORBITER PAYLOAD INTERROGATOR WOULD STILL BE USED TO EXECUTE SATELLITE.

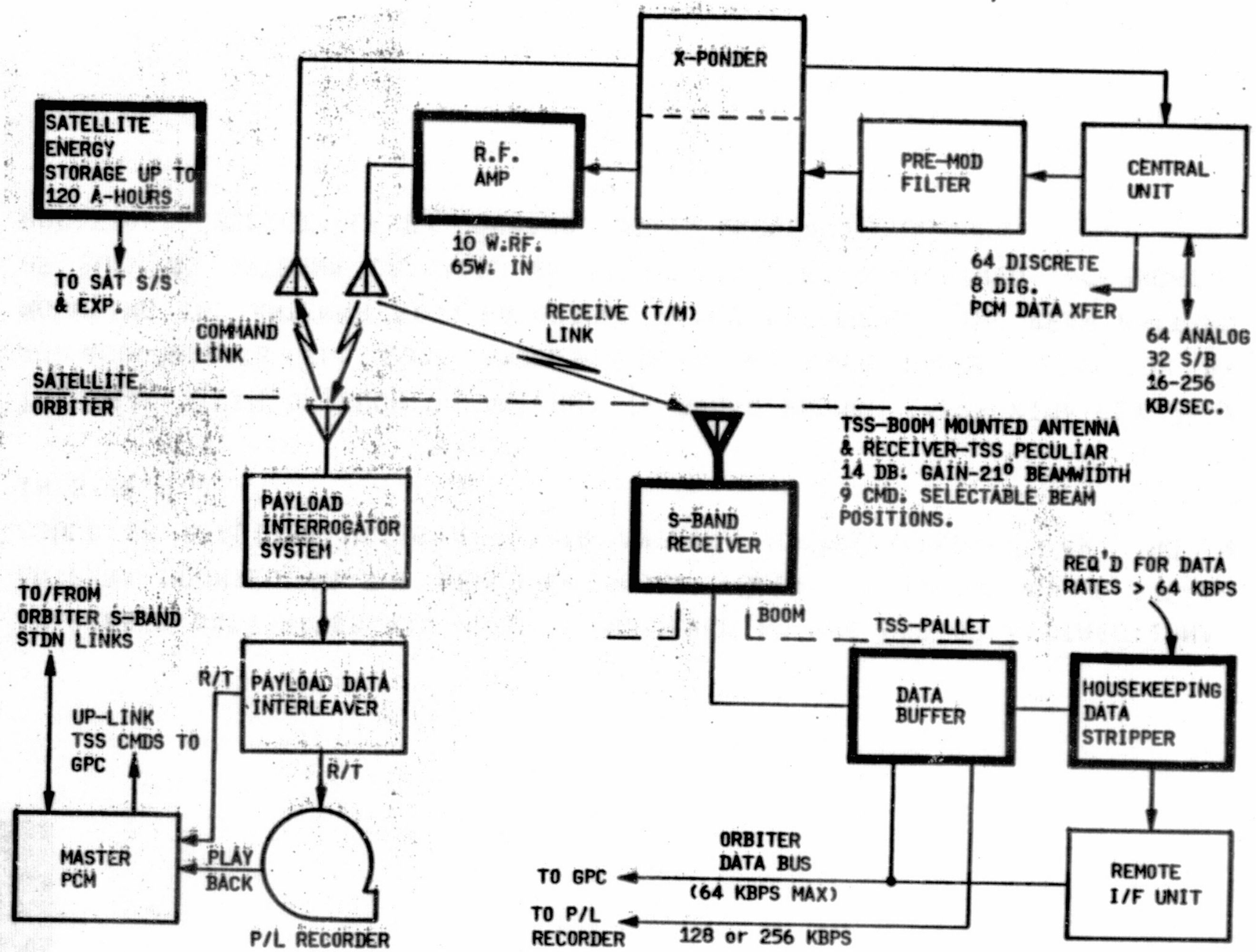
TSS COMMAND & DATA HANDLING – BASELINE SYSTEM



IF THE SATELLITE DATA RATES WERE INCREASED BY INCREASING THE SATELLITE RF POWER LEVEL, AND THE ON-STATION OPERATING TIME REMAINED THE SAME, AN INCREASED BATTERY COMPLEMENT IN THE SATELLITE WOULD BE REQUIRED. FOR DATA RATES UP TO 64 KBPS THE SATELLITE DATA WOULD BE BUFFERED AT THE PALLET-MOUNTED RECEIVER AND FED TO THE ORBITER GENERAL PURPOSE COMPUTER DATA BUFFERING SYSTEM.

FOR DATA RATES EXCEEDING 64 KBPS THE DATA WOULD BE RECORDED DIRECTLY, BYPASSING THE GENERAL PURPOSE COMPUTER. HOUSEKEEPING DATA WOULD BE STRIPPED BY A TSS PECULIAR UNIT, LOCATED ON THE PALLET AND BUFFERED AT A RATE LESS THAN 64 KBPS TO THE GENERAL PURPOSE COMPUTER.

MODIFICATIONS TO ACHIEVE HIGHER DATA RATE



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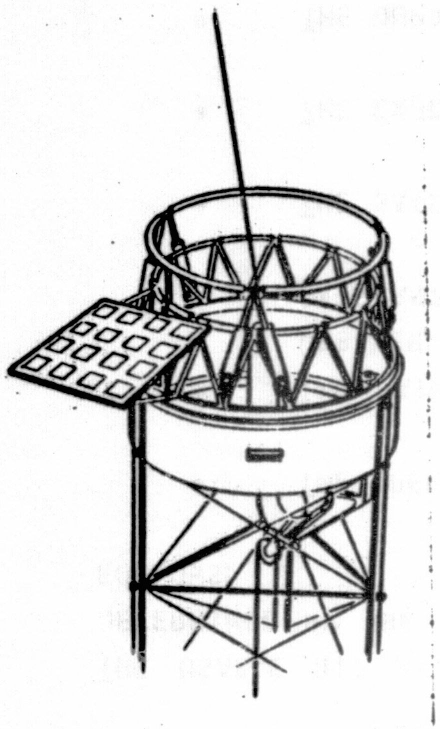
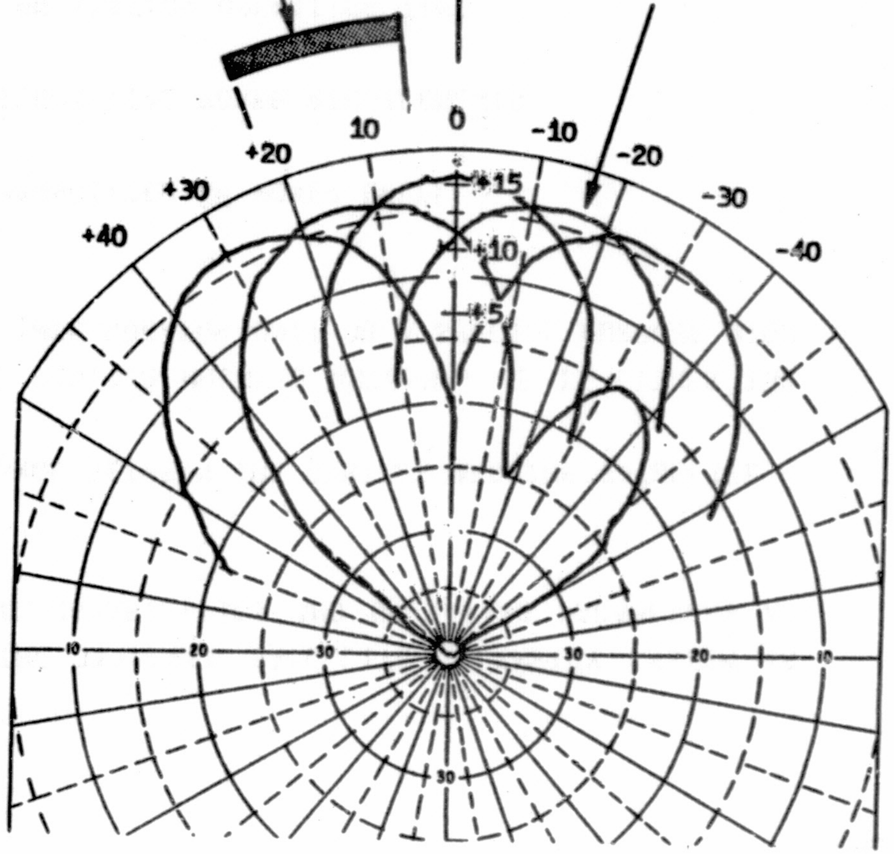
INCREASED DATA RATES MAY ALSO BE ACHIEVED BY THE USE OF A DIRECTIONAL ANTENNA MOUNTED ON THE DEPLOYER BOOM. GAINS OF UP TO ABOUT +15 dB COULD BE REALIZED USING A PLANAR ANTENNA APPROXIMATELY 50 CM X 50 CM IN SIZE.

THE BEAM WIDTH OF SUCH AN ANTENNA IS BROAD ENOUGH (APPROXIMATELY 24°) TO ACCOMMODATE THE LOOK ANGLES FOR A SELECTED PALLET POSITION BY MOUNTING THE ANTENNA AT A FAVORABLE PITCH ATTITUDE. THE BEAM PATTERN OF SUCH AN ANTENNA CAN ALSO BE STEERED TO PRE-DETERMINED INCREMENTAL POSITIONS, SELECTABLE BY COMMAND, USING PROVEN TECHNIQUES.

COMMAND-STEERABLE ANTENNA FOR INCREASING SATELLITE DATA RATE CAPABILITY



ELECTRONICALLY
STEERED ARRAY INSTALLED
ON DEPLOYER TOWER



MEASURED BEAM PATTERNS
4X4 ELEMENT-COMMAND
STEERABLE ANTENNA ARRAY

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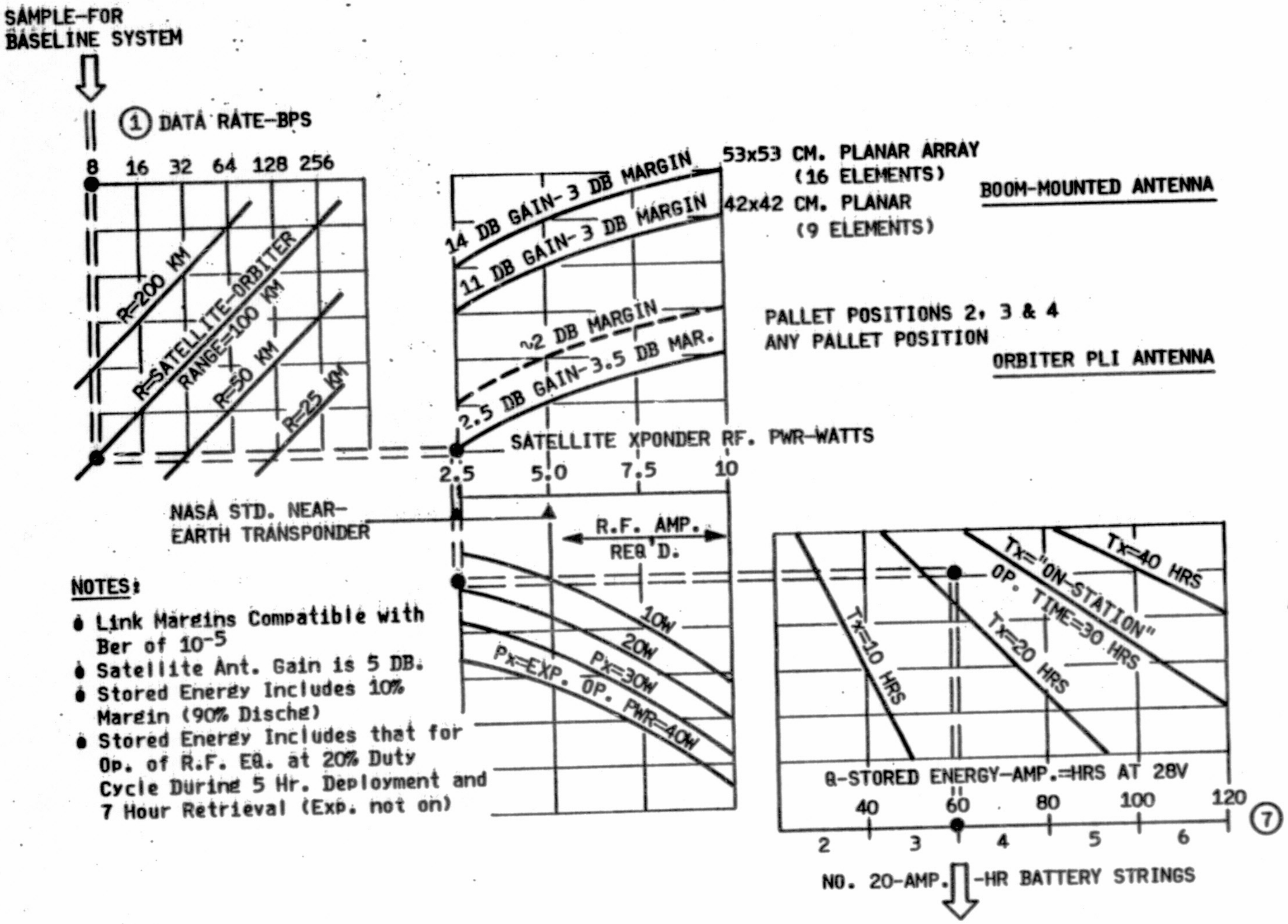
THE USABLE BIT RATE FOR THE TETHERED SATELLITE TELEMETRY SYSTEM IS DETERMINED BY THE COMPONENT CAPABILITIES AND OPERATING PARAMETERS AS FOLLOWS:

- THE OPERATING RANGE BETWEEN THE ORBITER AND THE SATELLITE
- THE GAIN OF THE ORBITER MOUNTED ANTENNA, BE IT EITHER THE ORBITER PAYLOAD INTERROGATOR UNIT OR A SPECIAL PURPOSE HIGH GAIN ANTENNA
- THE SATELLITE TRANSMITTER RF POWER LEVEL
- THE EXPERIMENT ELECTRICAL POWER REQUIREMENTS
- THE DURATION OF ON-STATION OPERATING TIME
- THE CAPACITY OF THE SATELLITE BATTERIES TO STORE ENERGY

THESE PARAMETERS ARE INTERRELATED IN THE ACCOMPANYING CHART ON WHICH IS SHOWN A TYPICAL EXAMPLE FOR THE BASELINE SYSTEM.

TETHERED SATELLITE SYSTEM–SATELLITE-TO-ORBITER DATA LINK PARAMETERS AND THEIR INTERDEPENDANCE



NOTES:

- Link Margins Compatible with Ber of 10^{-5}
- Satellite Ant. Gain is 5 DB.
- Stored Energy Includes 10% Margin (90% Dischg)
- Stored Energy Includes that for Op. of R.F. EQ. at 20% Duty Cycle During 5 Hr. Deployment and 7 Hour Retrieval (Exp. not on)

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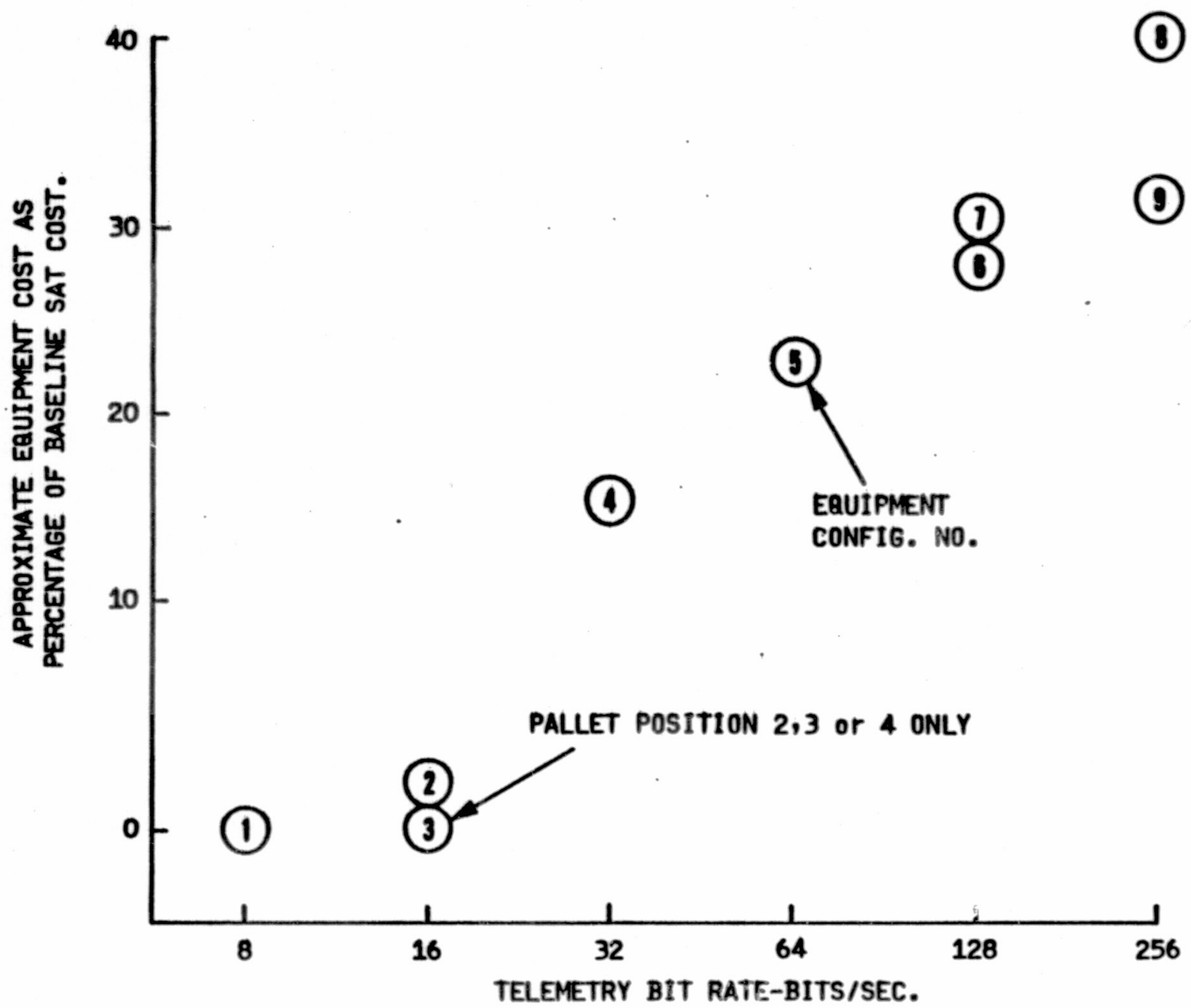
EQUIPMENT COMPLEMENTS–VARIOUS T/M CONFIGURATIONS REQUIRED TO INCREASE DATA RATE

CONFIGURATION NO.	1	2	3	4	5	6	7	8	9
BIT RATE-W/3.5 DB. MARGIN	8	16	16	32	64	128	128	256	256
-PALLET POS 2,3,4 ONLY			X						
SATELLITE EQUIPMENT									
NEAR EARTH TRANSPONDER									
2.5 WATT-R.F. OUT	X		X	X	X		X	X	
5.0 WATT-R.F. OUT		X				X			X
R.F. AMPLIFIER 10 WATT								X	
BATTERY COMPLIMENT									
QNTY 20 A-HR. STRINGS (23 HRS-"ON STATION")	3	4	3	5	3	4	3	5	4
ALL CONFIGURATIONS USE: MULTIPLEXER CENTRAL & REMOTE UNIT, PREMODULATION FILTER, COMMAND & RECEIVE PATCH ANTENNAS									
ORBITER-DEPLOYER EQUIPMENT									
DATA RECORDED:									
VIA P/L DATA INTERLV'R	X	X	X	X	X				
DIRECT (BYPASS GPC)						X	X	X	X
BOOM MTD. RECEIVER				X	X	X	X	X	X
BOOM MTD. ARRAY:									
11 DB. (9 ELEMENT)				X		X		X	
14 DB. (16 ELEMENT)					X		X		X
PALLET MTD. DATA BUFFER					X	X	X	X	X
HOUSEKEEPING DATA STRIPPER						X	X	X	X
ALL CONFIGURATIONS USE: PAYLOAD INTERROGATOR SYSTEM AND ASSOCIATED ANTENNA									

APPROXIMATE "DELTA" COSTS FOR EQUIPMENT TO INCREASE DATA RATE



INCREASED DATA RATE STUDY

- SATELLITE-TO-ORBITER DATA RATES. MAY BE INCREASED FROM BASELINE 8 KBPS ON UP TO 256 KBPS BY ADDITION OF A DIRECTIONAL ANTENNA AND SPECIAL EQUIPMENT ON THE DEPLOYER. COST INCREASES WOULD RANGE UP TO 40 PERCENT OF THAT FOR THE BASELINE SATELLITE (INCREASE TOTAL PROGRAM COSTS BY 12 TO 13 PERCENT).

SEVERAL METHODS FOR DETERMINING REAL TIME SATELLITE POSITION REQUIRE SOPHISTICATED EQUIPMENT, OR DO NOT PRODUCE CONTINUOUS DATA

- ORBITER-MOUNTED LASER TRACKING - NO KNOWN TRACKING EQUIPMENT AVAILABLE
- GLOBAL POSITIONING SATELLITE SYSTEM - NOT CONTINUOUS - REQUIRES TRANSPONDER AND ANTENNA ON SATELLITE
- KU-BAND RADAR - ACTIVE MODE - NO COMPATIBLE BEACON TRANSPONDER AVAILABLE
- S-BAND-BEACON (COMBINED WITH DATA LINK SYSTEM) - NO FLIGHT QUALIFIED INTERROGATOR AVAILABLE
- TONE RANGING INTERFEROMETER - NO FLIGHT QUALIFIED HARDWARE. PROBABLE BOOM INTERFERENCE WITH ANTENNA PATTERNS. COMPLEX DATA REDUCTION. AMBIGUITIES IN DATA.
- GROUND BASED NETWORKS - STDN, DMA - NOT CONTINUOUS

SEVERAL "ON-BOARD" METHODS - TSS UNIQUE-ARE AVAILABLE FOR REAL-TIME POSITION DETERMINATION

ALTERNATIVE METHODS

- ACCELLEROMETERS ON SATELLITE - FAIRLY COMPLEX ON-BOARD SOFTWARE REQUIRED TO EXTRACT ACCELERATION COMPONENTS INDICATIVE OF LIBRATION POSITION
- ATTITUDE DATA FROM ORBITER (IN DRIFT MODE) CAUSED BY RE-ACTION OF TETHER - ACCURACY DEGRADES AT SHORT RANGES. ANGULAR DATA ONLY

SELECTED METHOD

- PASSIVE TRACKING BY KU-BAND ORBITER RENDEZVOUS RADAR - REQUIRES ENHANCEMENT OF SATELLITE RADAR CROS-SECTION - REQUIRES REMOVAL OF RANGE AMBIGUITIES
- TURNS-COUNTER ON TETHER DE-PLOYER - RANGE ONLY - MUST BE COMPENSATED FOR STRETCH OF TETHER
- ORBITER CLOSED CIRCUIT TV CAMERAS LOCATED ON PALLET - GOOD FOR RANGES LESS THAN 400 METERS FINAL RETRIEVAL PHASE - ONLY APPROXIMATE RANGE DATA

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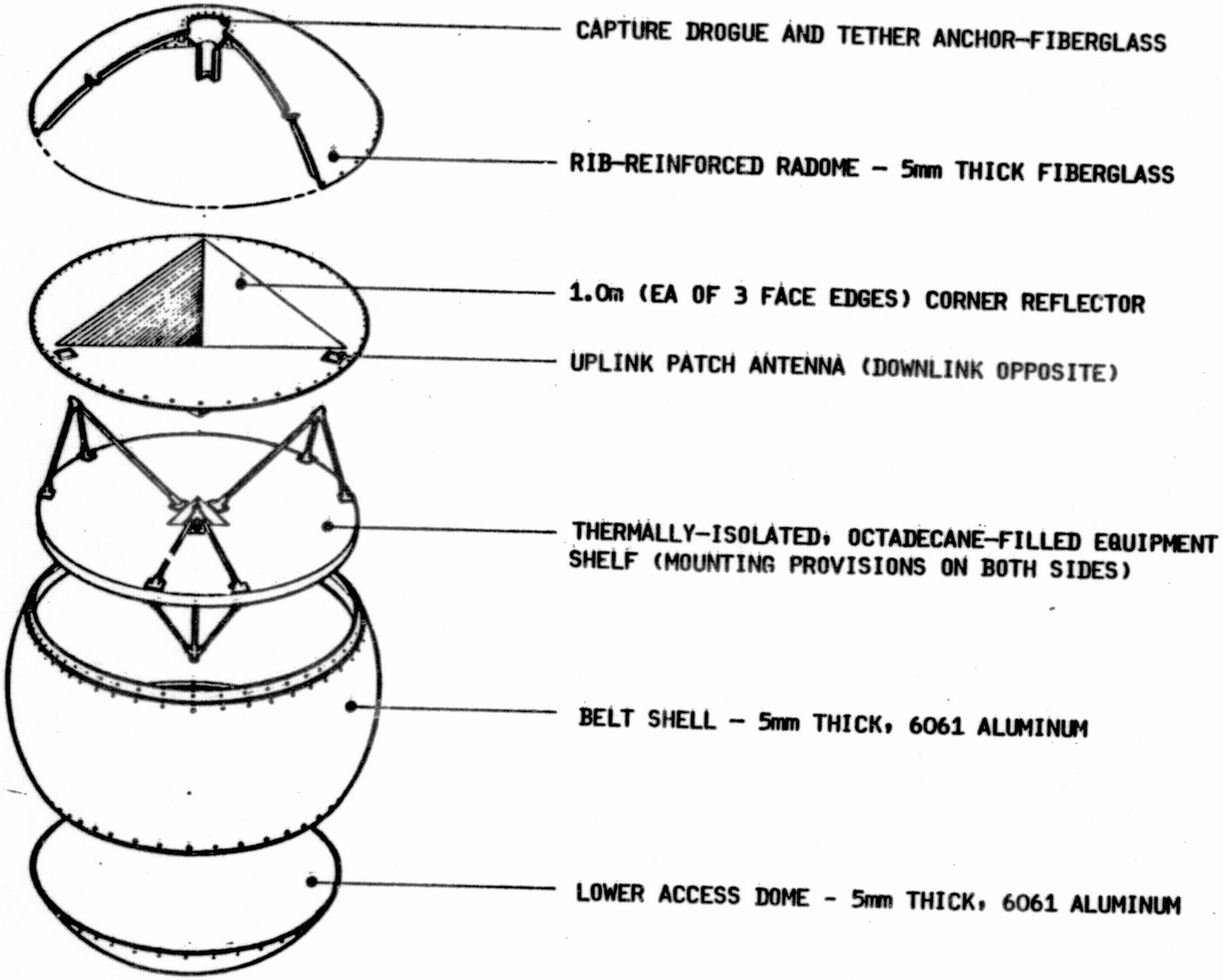
ALTERNATIVE METHODS OF SATELLITE POSITION DETERMINATION

EQUIPMENT COMPLEMENT

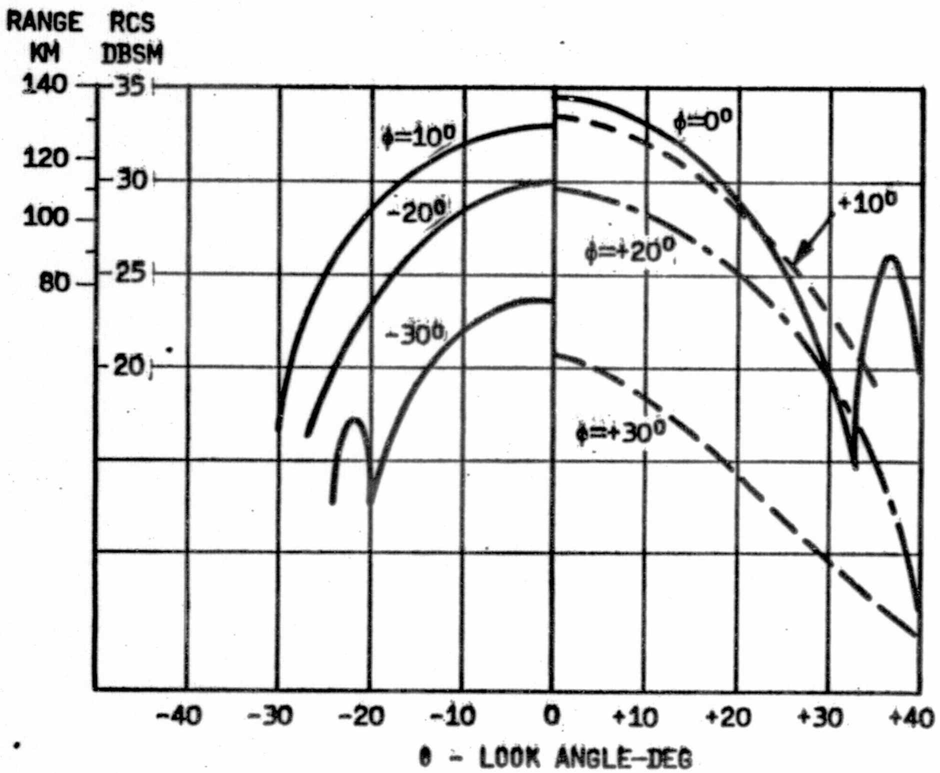
FUNCTION	METHOD	ORBITER KU-BAND: ORBITER: KU-BAND RADAR	ORBITER KU-BAND: SATELLITE: CORNER REFLECTOR	ORBITER KU-BAND: SATELLITE: KU-BAND X-PONDER	TSS SUPPLIED-S-BAND: DEPLOYER: RANGING INTEROGTR	TSS SUPPLIED-S-BAND: DEPLOYER: DOME ANTENNA	TSS SUPPLIED-S-BAND: SATELLITE: RANGING X-PONDER	POSSIBLE CALIB. OR INDIRECT RNG.: TETHER LENGTH MEAS	POSSIBLE CALIB. OR INDIRECT RNG.: GND BASED POS. MEAS.	CONVENTIONAL COMMUNICATIONS EQUIPMENT: DEPLR.	CONVENTIONAL COMMUNICATIONS EQUIPMENT: SATELT.
ANGULAR POSITION 0-19Km	A	X									
19-100Km	B	X	X(1)								
	C	X		X(2)							
	D					X(3)				X	X
RANGING 0-19Km	E	X						X			
19-100Km	F	X	X(1)								
	G	X		X(2)							
	H				X(4)		X(5)				
	I							X	X		

NOTES:
(1) MODERATE RESTRICTIONS ON USEABLE ANGULAR RANGE
(2) KU-BAND TRANSPONDER NEITHER PRESENTLY AVAILABLE NOR UNDER DEVELOPMENT (COST)
(3) BASD DOME (HEMISPHERICAL) ANTENNA NOT FLIGHT QUALIFIED (COST)
(4) NO FLIGHT QUALIFIED, FLIGHT PACKAGED, RANGING INTERROGATOR AVAILABLE
(5) REQUIRES USE OF NASA STANDARD OR SIMILAR RANGING TRANSPONDER (COST)

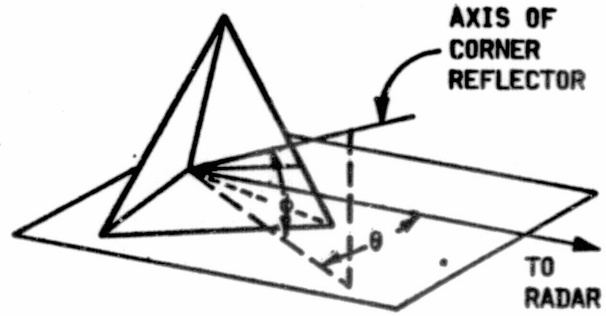
TETHERED SATELLITE EQUIPPED WITH CORNER REFLECTOR TO ENHANCE RADAR CROSSECTION



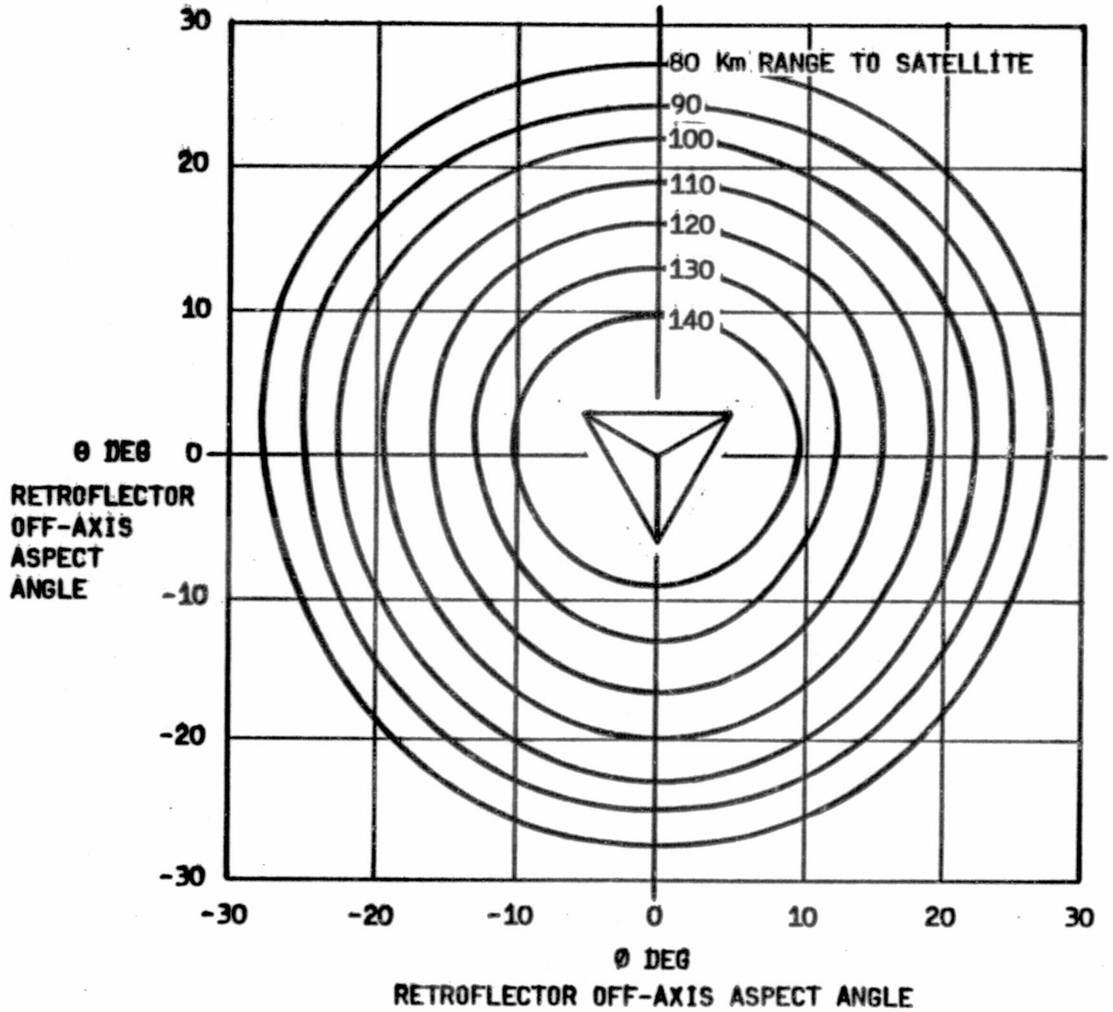
RADAR CROSSECTION AND TRACKING RANGE FOR 1 MTR/SIDE CORNER REFLECTOR



Corner Reflector Coordinate System.



USEABLE SATELLITE TRACKING RANGE FOR ORBITER RENDEZVOUS RADAR – 1 MTR/SIDE CORNER REFLECTOR



POSITION DETERMINATION - STUDY RESULTS

MOST PROMISING AND COST-EFFECTIVE REAL-TIME POSITION DETERMINATION SYSTEM WOULD INVOLVE USE OF THE ORBITER Ku-BAND RENDEZVOUS RADAR:

- THE SATELLITE WOULD BE EQUIPPED WITH A RETROREFLECTOR TO ENHANCE ITS RADAR CROSS-SECTION
- THE RADAR WOULD BE USED IN THE "PASSIVE" MODE. AMBIGUITIES IN RANGE DATA (DUE TO SHORT DURATION RANGE GATE) WOULD BE REMOVED BY COMPARING WITH ROUGH RANGE DATA DERIVED FROM DEPLOYED TETHER LENGTH
- CONFIRMATION OF THIS MODE OF OPERATION (OF THE ORBITER RENDEZVOUS RADAR), AND THE EFFECT OF GROUND CLUTTER SHOULD BE CONFIRMED BY ANALYSIS OR RADAR SYSTEM TESTS

SATELLITE POSITION COULD ALSO BE DETERMINED BY DATA FROM SENSITIVE ACCELEROMETERS LOCATED IN THE SATELLITE:

- SUBSTANTIAL DATA REDUCTION WOULD BE REQUIRED
- DERIVING DATA IN REAL-TIME DURING FLIGHT WOULD REQUIRE FAIRLY SOPHISTICATED ON-BOARD SOFTWARE.

F80-10

2000 - SCIENCE ACCOMMODATION STUDY

TETHERED SATELLITE - EXPERIMENT ACCOMMODATION REQUIREMENTS

	BASELINE	MAGNETOMETER	ELECTRODYNAMICS	CHEM. RELEASE	ATMOSPHERIC	
MISSION REQUIREMENTS						
Orbiter Altitude (Km)	230	ANY	ANY	ANY	ANY	(5) High Inclination Preferred
Orbit Inclination (°)	ANY	LO-OK(5)	LO-OK(5)	LO-OK(5)	LO-OK(5)	
Satellite Alt. (Km)	230-130	130	230-240	160-120	150-125	
Tether Length (Km)	100	90	10-20	N/A	N/A	
Typical Mission Duration-Days	7		N/A	6		
Exp. Op. Time On Sta. (Hrs)	23	23	18	(7)		(7) 10 Separate Releases
Desired Earth Cov. Pattern	N/A		N/A	(8)	Full Orbits	(8) Proximity of Earth Obs. Sites
Direction of Sat. Deployment	Down	Down	Up	Down	Down	
Near Real Time Com. to POOC	Yes	Yes	Yes	Yes	Yes	
SATELLITE POSITION DETERMINATION						
Accuracy WRT-Orbiter						
Planar (Km)	$\pm$ 2	N/A	$\pm$ 3	N/A	--	
Altitude (Km)	$\pm$ 2	N/A	$\pm$ 1	N/A	--	
Accuracy WRT-Earth Coords						
Planar (Km)	$\pm$ 3	$\pm$ 3	$\pm$ 3	$\pm$ 5	$\pm$ 10(9)	(9) Along GND-Track
Altitude -(Km)	$\pm$ 3	$\pm$ 2	$\pm$ 3	$\pm$ 3	$\pm$ 1	

TETHERED SATELLITE - EXPERIMENT ACCOMMODATION REQUIREMENTS

	BASELINE	MAGNETOMETER	ELECTRODYNAMICS	CHEM. RELEASE	ATMOSPHERIC	
MISSION REQUIREMENTS						
Orbiter Altitude (Km)	230	ANY	ANY	ANY	ANY	
Orbit Inclination (°)	ANY	LO-OK(5)	LO-OK(5)	LO-OK(5)	LO-OK(5)	(5) High Inclination Preferred
Satellite Alt. (Km)	230-130	130	230-240	160-120	150-125	
Tether Length (Km)	100	90	10-20	N/A	N/A	
Typical Mission Duration-Days	7		N/A	6		
Exp. Op. Time On Sta. (Hrs)	23	23	18	(7)		(7) 10 Separate Releases
Desired Earth Cov. Pattern	N/A		N/A	(8)	Full Orbits	(8) Proximity of Earth Obs. Sites
Direction of Sat. Deployment	Down	Down	Up	Down	Down	
Near Real Time Com. to POOC	Yes	Yes	Yes	Yes	Yes	
SATELLITE POSITION DETERMINATION						
Accuracy WRT-Orbiter						
Planar (Km)	± 2	N/A	± 3	N/A	--	
Altitude (Km)	± 2	N/A	± 1	N/A	--	
Accuracy WRT-Earth Coords						
Planar (Km)	± 3	± 3	± 3	± 5	± 10(9)	(9) Along GND-Track
Altitude -(Km)	± 3	± 2	± 3	± 3	± 1	

TETHERED SATELLITE - EXPERIMENT ACCOMMODATION REQUIREMENTS

	BASELINE	MAGNETOMETER	ELECTRODYNAMICS	CHEM. RELEASE	ATMOSPHERIC	
TETHER REQUIREMENTS						
Length - Km (11)	100	100	10-20	90	90	(11) With Orbiter at 220 Km. Alt.
Type (Non-Cond., Cond., Ins. Cond)	Non-Cond.	Non-Cond.	Ins.Cond.	Any	Non-Cond.	
Resistivity - Ohm/Mtr.	N/A	N/A	0.2	N/A	N/A	
Leakage Resistance-Ohm/Mtr	N/A	N/A	10^{13}	N/A	N/A	
Breakdown Strength-Kv.	N/A	N/A	3	N/A	N/A	
ORBITER-MOUNTED, EXP-PECULIAR EQUIPMENT						
Volume - MTR^3	None	None	0.1(17)	None	None	
Weight - Kg.	None	None	30(17)	None	None	(17) Estimate
Location - AFD, Pallet, Other	None	None	Pallet	None	None	
Ave. Power - Watts	None	None	40 (Min)	None	None	
Operating Time - Hrs.	None	None		None	None	

TC-20-2

TETHERED SATELLITE - EXPERIMENT ACCOMMODATION REQUIREMENTS

	BASELINE	MAGNETOMETER	ELECTRODYNAMICS	CHEM. RELEASE	ATMOSPHERIC	
SATELLITE STRUCTURE & MECHANISM						
Exper. Equip. Weight - Kg.	--	4	50	242	24	
Exper. Equip. Volume - MTR.^3	--	.01	.04	.15	.032	
Total Satellite Weight - KG	308	310	312	546	340	
Experiment Aperture	None	None	13	10	4	(13) 2 Surface Probes
Experiment External Components	None	Sensor		None	None	
Experiment Deployable Booms	1(1)	1(1)	1	(10)	None	(1) Avail. for Exp. Use (10) Ejectable Cannisters 10 Ea.
SATELLITE POWER/ENERGY STORAGE						
Experiment On-Time- Hrs.	35	35	18	N/A	31	
Exp. Average Power- Watts	12	5	25	None	30	
Exp. Stored Energy Req'd-W/Hrs.	420	175	450	Nil	930	
Total Stored Energy (S/C + Exp.) A-Hrs. @ 28V.	60	60	80	Nil	80	
No. 20 A-Hr. Batt Packs	3	3	3	3	5	

TETHERED SATELLITE - EXPERIMENT ACCOMMODATION REQUIREMENTS

	BASELINE	MAGNETOMETER	ELECTRODYNAMICS	CHEM. RELEASE	ATMOSPHERIC	
COMMAND & DATA HANDLING						
Exp. Discrete Commands-Qty.	15(5)	16	16	20	12	(5) 24 Unassigned Spares
Exp. Serial Commands-Qty (16 Bit)	8	4	8	None	8	
PCM Data-Rate-BPS	2	2	-	-	-	
No Exp. Housekeeping Channels (0-5 Analog to 8 Bit Dig)	11(3)	16	10	20	Not Spec	(3) Also 12 Spares avail.
No Exp. Bilevel Indicators	12(4)	12	12	10	Not Spec	(4) Also 10 Spares Avail.
PCM Digital Data Rate-KBPS	8	8	30(14)	N/A	8	(14) At 20 Km. range

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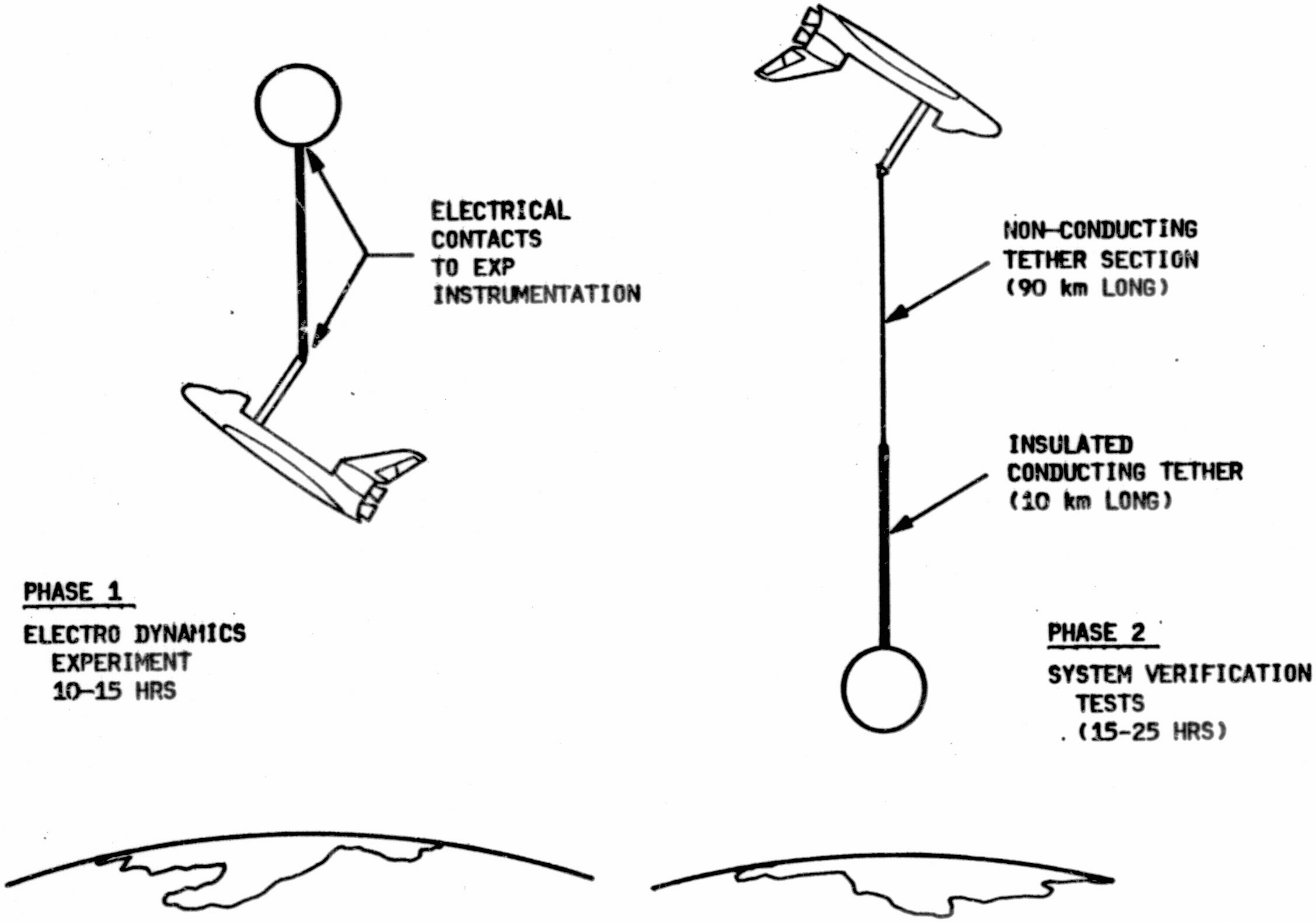
2100 – ELECTRODYNAMICS EXPERIMENT ACCOMMODATION

ELECTRO DYNAMICS MISSION PHASES



PHASE 1

ELECTRO DYNAMICS
EXPERIMENT
10-15 HRS

PHASE 2

SYSTEM VERIFICATION
TESTS
(15-25 HRS)

MISSION REQUIREMENTS - ELECTRODYNAMIC TETHERED SATELLITE SYSTEM

- ORBITER ALTITUDE - 200 KM (MIN.)
- ORBIT INCLINATION - HIGH INCLINATIONS PREFERRED
  LOW INCLINATION (28°) OK
- DEPLOYMENT DIRECTION - UP
- LAUNCH WINDOW - TO RESULT IN B-ANGLE > 45°, I.E. BEST ORIENTATION IS WITH LINE OF SIGHT TO SUN NORMAL TO ORBIT PLANE. (PRESENTS LEAST DEMAND ON ORBITER COOLING SYSTEM)
- TETHER LENGTH - 10 KM (MINIMUM)
  (100 KM LATER MISSIONS)
- DURATION OF "ON STATION" FLIGHT - 6 HOUR (MINIMUM) PERIODS
  AS MANY PERIODS AS FEASIBLE
- EXPERIMENT OPERATIONAL DUTY CYCLE - 100%-FROM SATELLITE SEPARATION
  UNTIL RECAPTURE

OPERATIONAL SUPPORT FUNCTIONS

- PAYLOAD OPERATIONS CONTROL CENTER - NEAR REAL-TIME MONITORING AND CONTROL OF EXPERIMENT
- ORBITER COMMAND AND DATA LINK - MAX DELAY, POCC TO/FROM ORBITER AND SATELLITE - TBD
- ORBITER EXPERIMENT SUPPORT FUNCTIONS:
  - REAL TIME MONITORING OF EXPERIMENT HOUSEKEEPING STATUS (SATELLITE AND PALLET-MOUNTED EQUIPMENT)
  - MULTIPLEX DATA AND FORMAT COMMANDS TO/FROM DOWN LINK
  - RECORD, CONTINUOUSLY, SATELLITE AND PALLET EXP. DATA
  - MEASURE SATELLITE POSITION RELATIVE TO ORBITER
    "REAL TIME" - MAX DELAY 5 MINUTES,
    INTERVALS OF 15 MINUTES
- ORBITER ATTITUDE - Y - PERPENDICULAR TO ORBIT PLANE
  +Z - ALONG LOCAL VERTICAL (PAYLOAD BAY DOORS UP)

TETHER REQUIREMENTS

- CONDUCTOR ELECTRICAL RESISTANCE - MAX - 0.2 OHM/MTR (0.02 OHM/MTR LATER MISSIONS)
- INSULATION LEAKAGE RESISTANCE - MINIMUM - 10^{13} OHM/METER
- INSULATION BREAKDOWN POTENTIAL - MINIMUM - 3,000 VOLTS (30,000 VOLTS LATER MISSIONS)
- CONDUCTOR TERMINATION AT SATELLITE AND ORBITER — INSULATED - TERMINATED IN EXPERIMENT ELECTRONICS

ELECTRODYNAMICS EXPERIMENT ACCOMMODATION – SATELLITE SUBSYSTEM REQUIREMENTS

- EXPERIMENT ELECTRICAL POWER

STANDBY - CONTINUOUS WHEN NOT PULSING	15 WATTS
AVERAGE OVER MISSION DURATION (INCLUDING PAYOUT AND RETRIEVAL PERIODS)	25 WATTS
PEAK - "OCCASIONAL" PERIODS OF SEVERAL MINUTES DURATION	200 WATTS

- COMMANDS, VIA ORBITER PAYLOAD INTERROGATOR LINK

DISCRETE - ON - OFF - COMMANDS	32 (ASSUMED)
MAGNITUDE COMMANDS - 16 BIT - SERIAL	8

- DATA HANDLING, VIA ORBITER PAYLOAD INTERROGATOR

BILEVEL STATUS INDICATORS	32
HOUSEKEEPING ANALOG STATUS CHANNELS - 8 BIT	32
MAIN FRAME EXPERIMENT DATA RATE, (10 KM TETHER LENGTH-6 DB MARGIN)	30 KBPS

SATELLITE ELECTRICAL POWER REQUIREMENTS

	AVG. LOAD WATTS	ENERGY CONSUMED (WATT-HRS)*
TRANSPONDER - TRANSMIT	17	391
- RECEIVE	2	46
DATA H & C - CENTRAL UNIT	11	253
REMOTE INTERFACE UNIT	3	69
ENG. INST. (INCLUDING ATT. DETER.)	3	69
ELECTRO DYNAMICS EXP.	25	575
	60	1,403 WATT HRS. (54 A.HRS. AT 26V.)

*DURING 23 HR. MISSION CONSISTING OF:

2 HOUR DEPLOYMENT
18 HOURS ON STATION AT 10 KM.
3 HOUR RETRIEVAL

ELECTRODYNAMICS EXPERIMENT ACCOMMODATION – SATELLITE SUBSYSTEM REQUIREMENTS(cont,d)

- SATELLITE ATTITUDE CONTROL

  RELATIVE TO NADIR - NOMINAL "FREE" POSITION
  AZIMUTH (ABOUT LOCAL VERTICAL) - SLOW ROTATION - UP TO 1 RPM

- SATELLITE ATTITUDE DETERMINATION ACCURACY - ± 5°

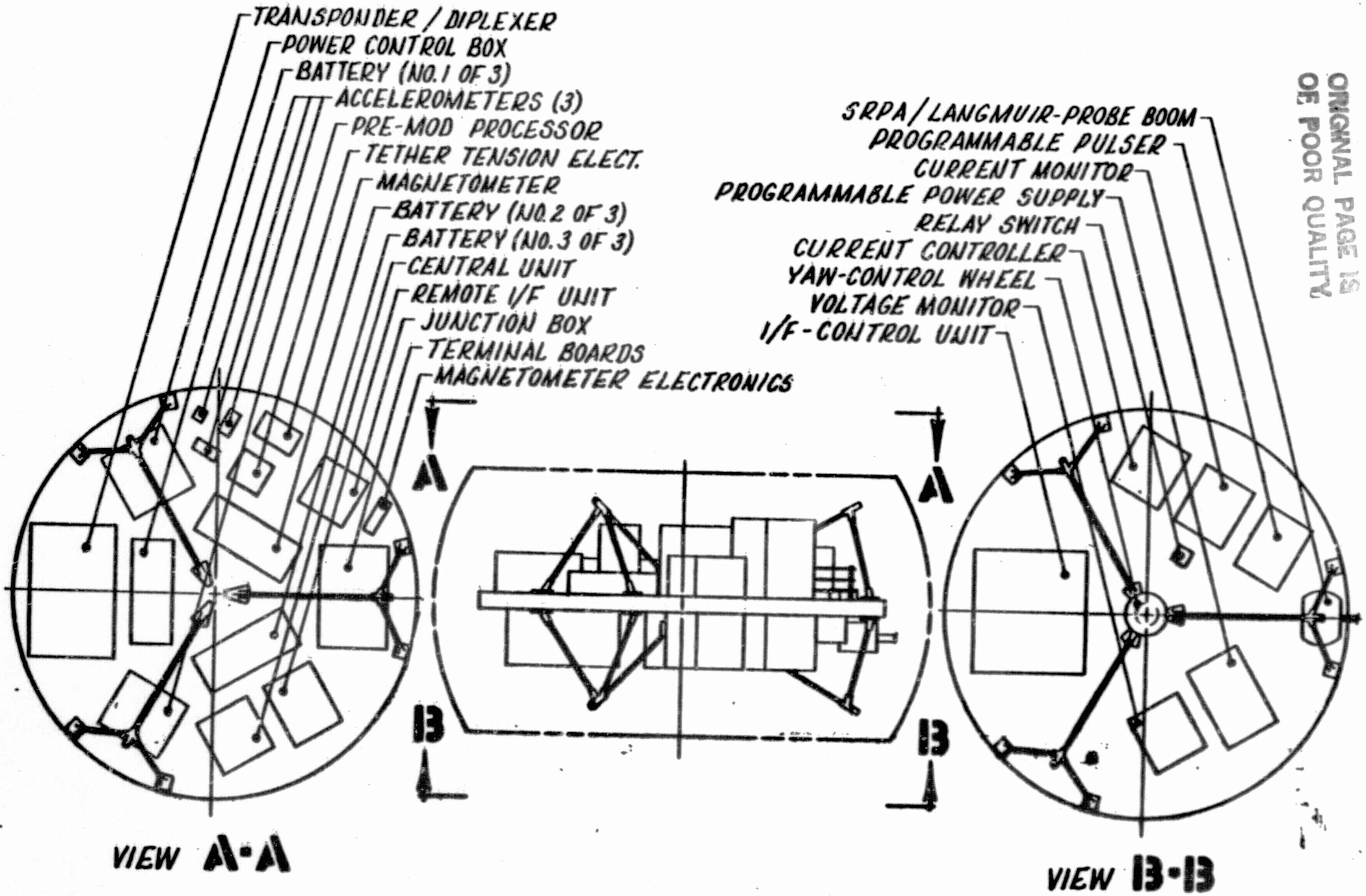
  RE VEL - VECTOR AND EARTH COORDS

- EXTERNAL SATELLITE FEATURES - SMOOTH CONDUCTING SPHERE

- INTERNAL EQUIPMENT TEMPERATURES

MAX. & MIN. DURING OPERATION	+10°C TO 55°C
SURVIVAL RANGE	-20°C TO +70°C

SATELLITE INTERNAL ARRANGEMENT FOR ELECTRODYNAMICS TSS



ELECTRODYNAMIC EXPERIMENT EQUIPMENT ON SATELLITE

	DIMENSIONS CM (IN.)	WEIGHT KG (LBS)
PROGRAMMABLE HIGH-VOLTAGE POWER SUPPLY	16.0x16.5x25.4(6.3x6.5x10.0)	6.8 (15.0)
PROGRAMMABLE PULSER (FAST-SWITCH SYSTEM)	7.6x15.2x20.3(3.0x6.0x8.0)	2.3 (5.0)
VOLTAGE MONITOR	16.0x16.5x17.8(6.3x6.5x7.0)	4.5 (10.0)
TOTAL-CURRENT MONITOR	16.0x16.5x17.8(6.3x6.5x7.0)	4.5 (10.0)
CURRENT CONTROLLER	16.0x16.5x17.8(6.3x6.5x7.0)	4.5 (10.0)
SATELLITE INTERFACE-CONTROL UNIT	16.0x16.5x35.6(6.3x13.0x14.0)	18.1 (40.0)
RELAY SWITCH	2.5x5.1x5.1(1.0x2.0x2.0)	0.9 (2.0)
CHARGE PROBE	3 DIA. (1.2 DIA.)	0.2 (0.5)
CURRENT PROBES (MONITORS) (5)	3 DIA. (1.2 DIA.)	1.1 (2.5)
SRPA/LANGMUIR PROBE	10/1 DIA'S. (3.9/0.4 DIA.)	2.3 (5.0)
		45.2(100.0)
EXPERIMENT-PECULIAR SATELLITE EQUIPMENT:		
PROBE BOOM (STOWED DIMENSIONS)	8.9x11.2x15.2(3.5x4.4x6.0)	0.9 (2.0)
YAW-CONTROL WHEEL	12.7DIA.x5.1 (5.0 DIAx2.0)	2.3 (5.0)
GOLD SURFACE FINISH	N/A	1.6 (3.5)
		4.8 (10.5)
		50.0(110.5)

WEIGHT SUMMARY – ELECTRODYNAMICS TETHERED SATELLITE

SUBSYSTEM	WEIGHT KG	WEIGHT LBS
STRUCTURES AND MECHANISM	177	389
COMMAND AND DATA HANDLING	10	221
ELECTRICAL POWER	48.3	106
ENGINEERING INSTRUMENTATION (INCLUDING ATT. DETER)	5	11
THERMAL CONTROL	13	29
ELECTRODYNAMICS EXPERIMENTS	57.5	127
TOTAL	311 KG	684 LBS

NOTE: ALL WEIGHT ESTIMATES INCLUDE 15% CONTINGENCY

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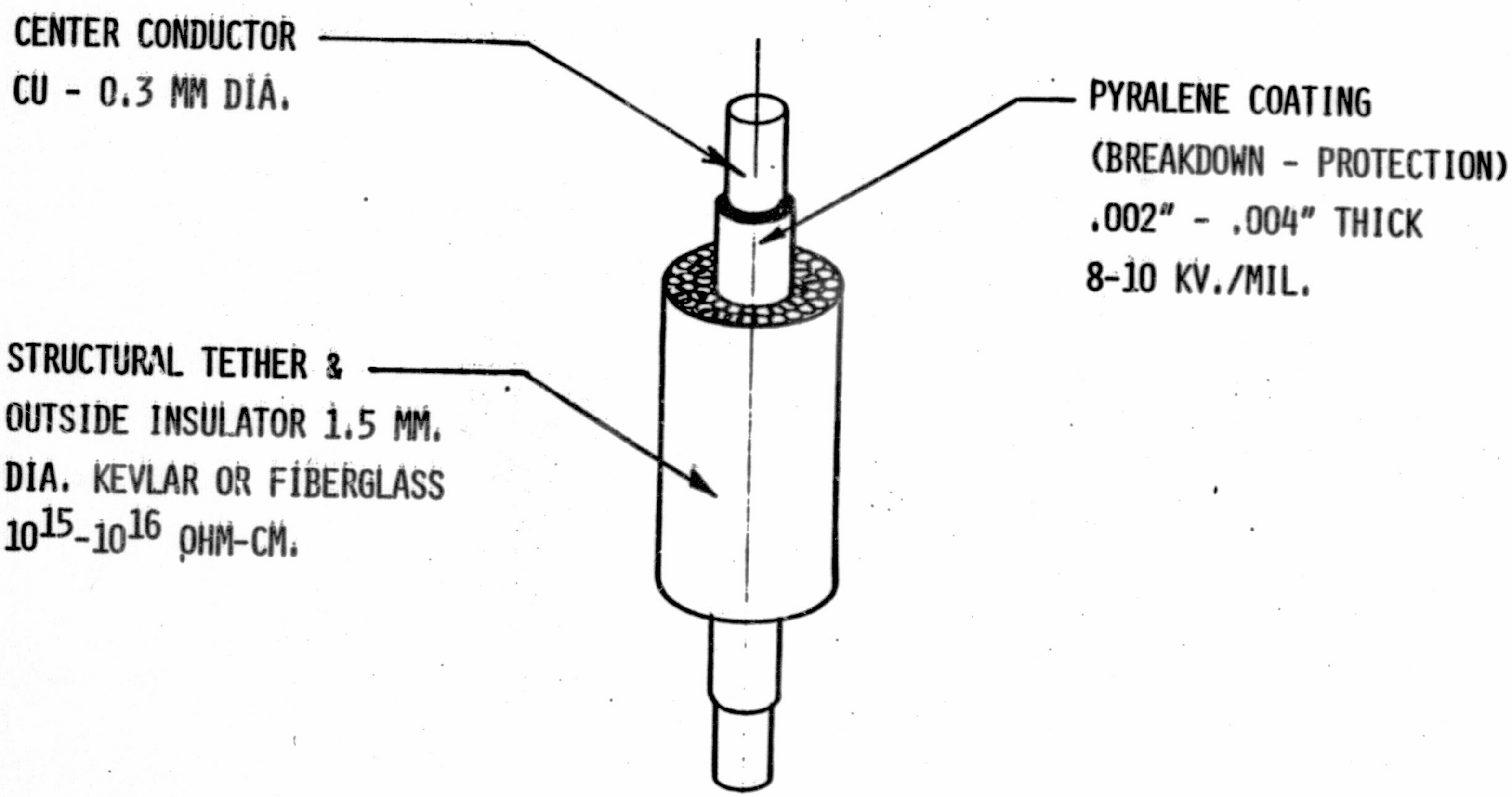
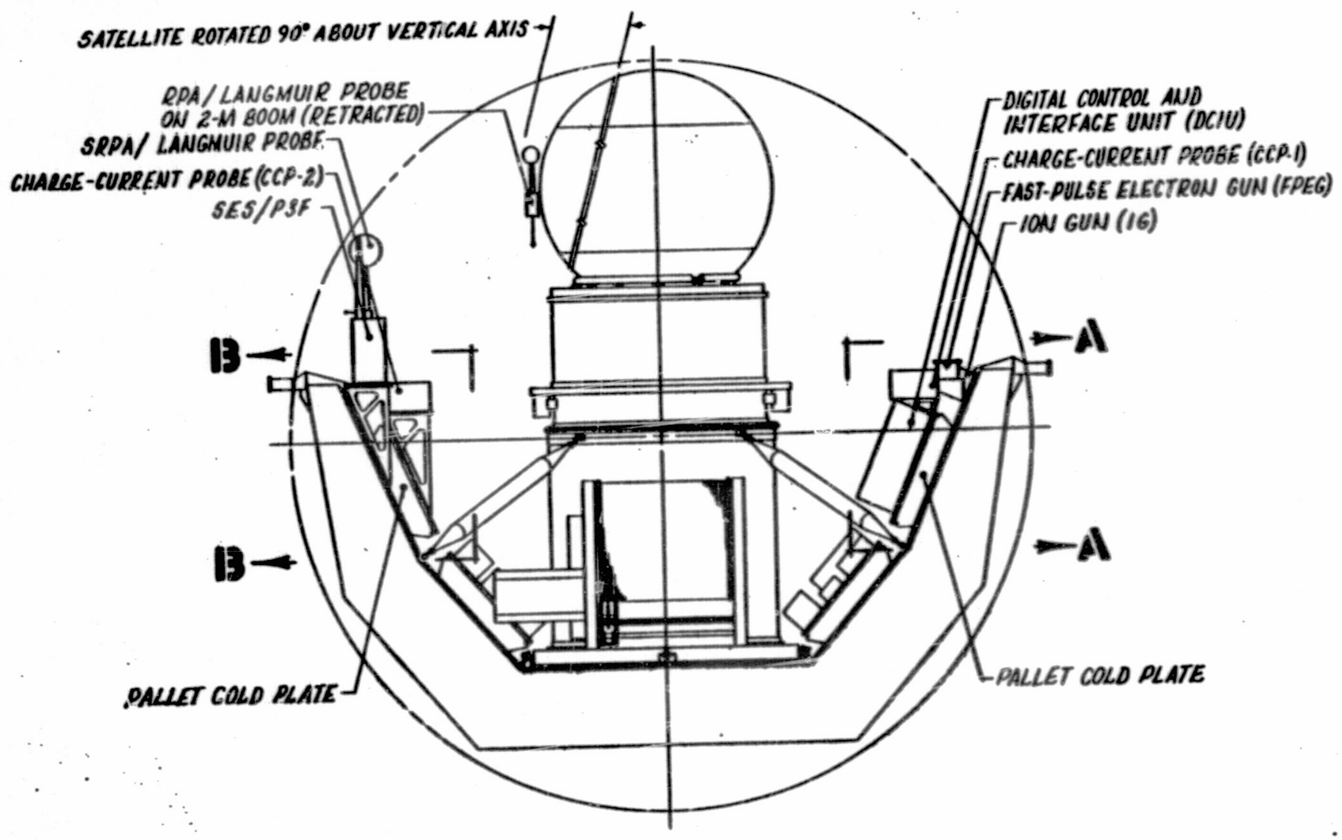
INSULATED TETHER PROPERTIES

	VERIFICATION MISSION	FOLLOW-ON MISSION
EXPERIMENT REQUIREMENT		
TETHER LENGTH - KM	10-20	100
LEAKAGE RESISTANCE-OHM/MTR-MAX.	10^{13}	10^{13}
CONDUCTOR RESISTANCE-OHM/MTR-MAX.	0.2	0.02
PROBABLE TETHER CONFIGURATION		
CENTER CONDUCTOR MATERIAL	Cu	Cu
CENTER CONDUCTOR DIAMETER-MM.	0.3	1.1
CONDUCTOR COATING .002"-.004" TH.	PYRALENE	PYRALENE
OUTER "INSULATION" (STRUCTURAL)	KEVLAR/ FIBERGLASS	BOROSILICATE FIBERGLASS(?)
RESISTIVITY OF OUTER INSULATION OHM-CM	10^{16}	10^{16} - 10^{17}
REQUIRED OVERALL TETHER DIAMETER	1.45MM.	∼ 3MM.
REEL CAPACITY - REQ'D TETHER DIA.	140 KM	∼50 KM(?)

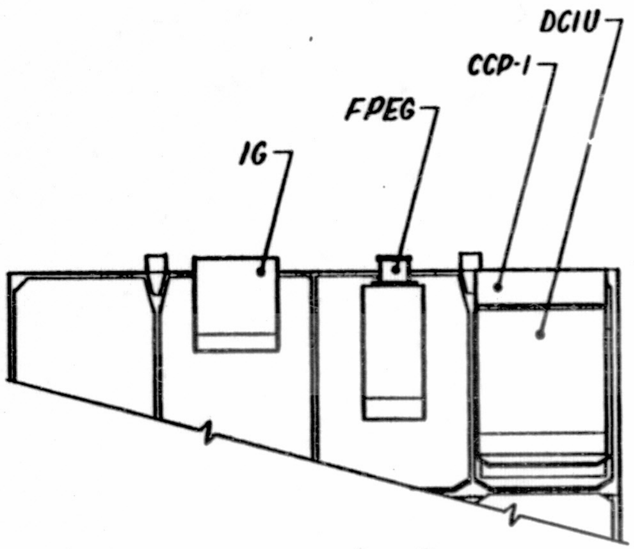
ELECTRODYNAMIC TETHER CONSTRUCTION - VERIFICATION MISSION



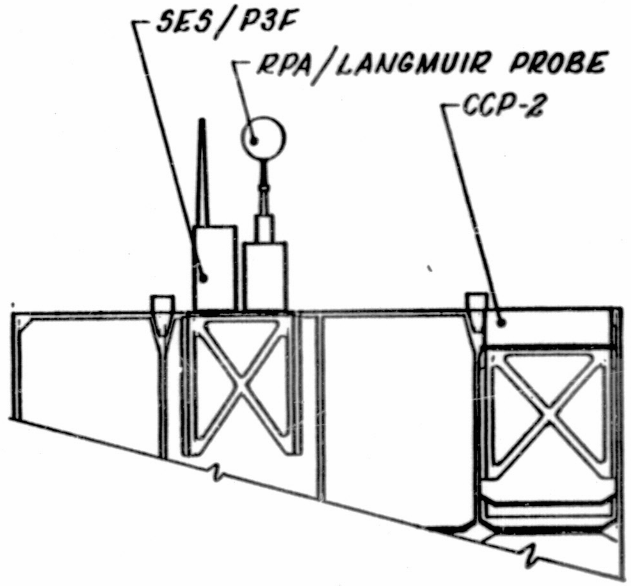
PALLET-MOUNTED AND SATELLITE-EXTERNAL EQUIPMENT FOR ELECTRODYNAMIC TSS



PALLET-MOUNTED AND SATELLITE-EXTERNAL EQUIPMENT FOR ELECTRODYNAMIC TSS (cont'd)



VIEW A-A



VIEW B-B

ACCOMMODATION IMPACT - ELECTRODYNAMIC EXPERIMENT

- ANALYZE/DEVELOP INSULATED TETHER WITH LEAKAGE, CONDUCTIVITY, AND HIGH VOLTAGE BREAKDOWN RESISTANCE IN ACCORDANCE WITH REQUIREMENTS. TETHER TO BE INSULATED FOR "LOWER" 10 KM. "UPPER" 90 KM TO BE NON-CONDUCTING MATERIAL.
- PROVIDE ELECTRICAL CONTACT AT ORBITER AND AT SATELLITE TETHER TERMINATIONS FOR CONNECTION TO EXPERIMENT EQUIPMENT.
- PROVIDE MECHANICAL, ELECTRICAL, AND THERMAL INTERFACE ACCOMMODATION ON DEPLOYER FOR DEPLOYER-MOUNTED EXPERIMENT EQUIPMENT.
- INCREASE SATELLITE BATTERY COMPLIMENT TO FOUR PACKS (80 AMP-HOURS).
- PROVIDE SMALL YAW REACTION WHEEL FOR INTRODUCING SLOW YAW ROTATION RATE INTO SATELLITE.
- PROVIDE SATELLITE MOUNTING FOR INSULATED, ELECTROSTATIC BOOM (SUPPLIED BY EXPERIMENTER).

ELECTRODYNAMICS EXPERIMENT ACCOMMODATION-STUDY RESULTS

- TETHER CONTRUCTION, WITH LOWER SECTION INSULATED AND CONDUCTING, IS FEASIBLE USING ESTABLISHED BRAIDING TECHNIQUES.

- HV-BREAKDOWN AND LEAKAGE CURRENT MECHANISMS TO EXTERNAL PLASMA ARE NOT WELL UNDERSTOOD. SOME DEVELOPMENTAL TESTING WOULD BE REQUIRED.

- BOTH "UPWARD" AND "DOWNWARD" DEPLOYMENTS ARE REQUIRED, WHICH WOULD SHORTEN THE AVAILABLE ON-STATION FLIGHT TIME AVAILABLE FOR BASELINE VERIFICATION TESTING.

F80-10

2200 - CHEMICAL RELEASE EXPERIMENT ACCOMMODATION

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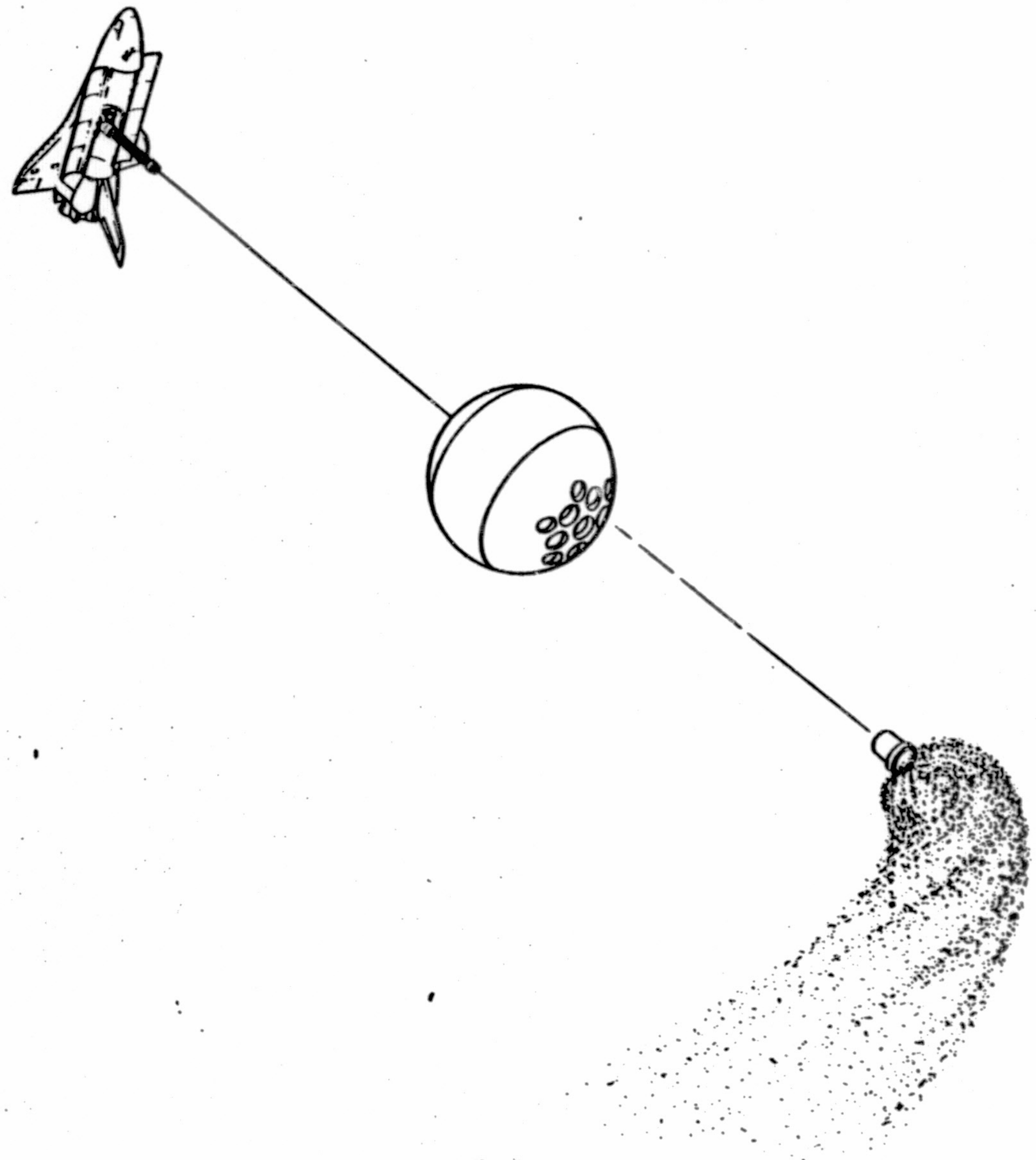
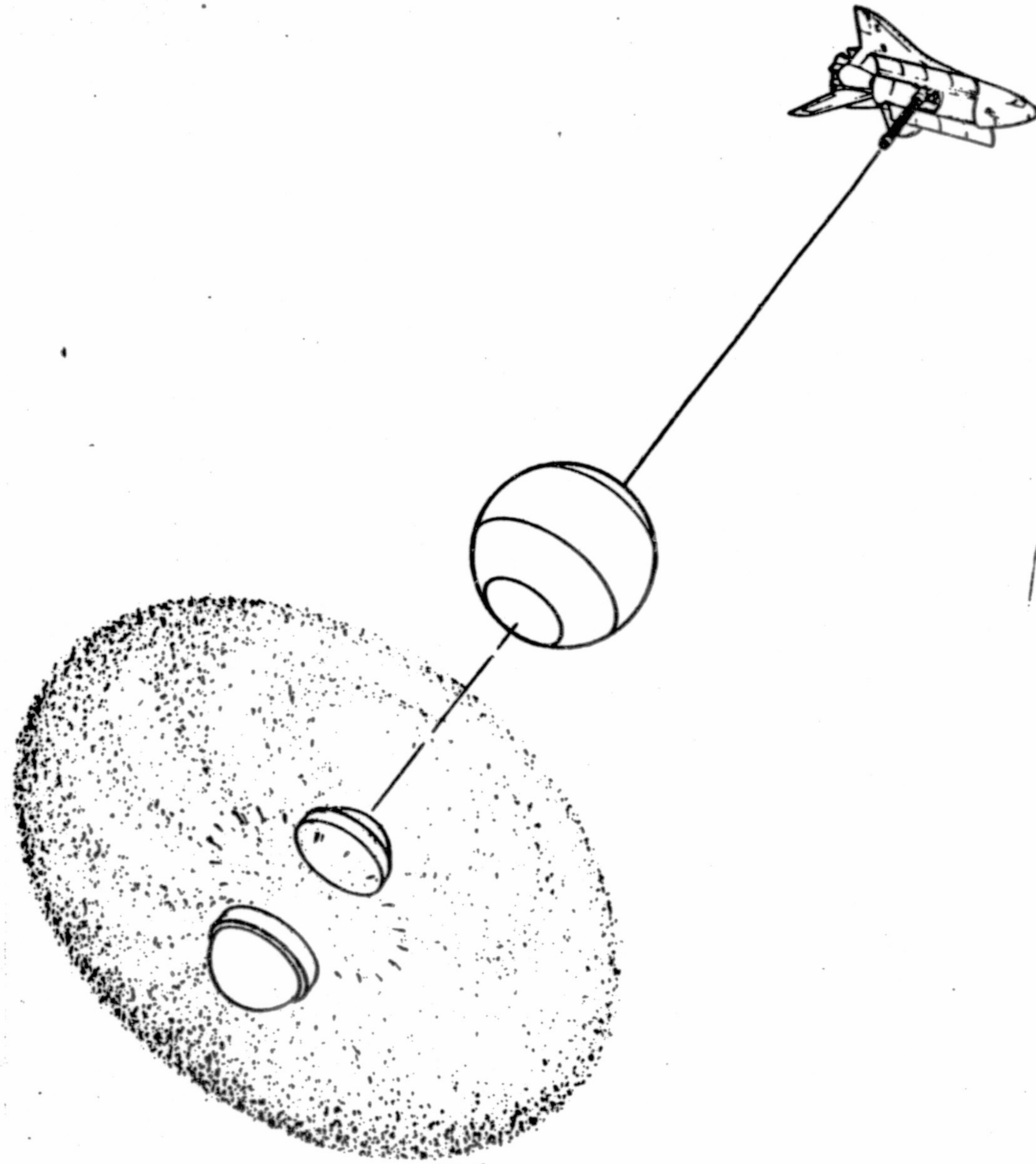
THERMITE RELEASE CONFIGURATION



GAS RELEASE CONFIGURATION



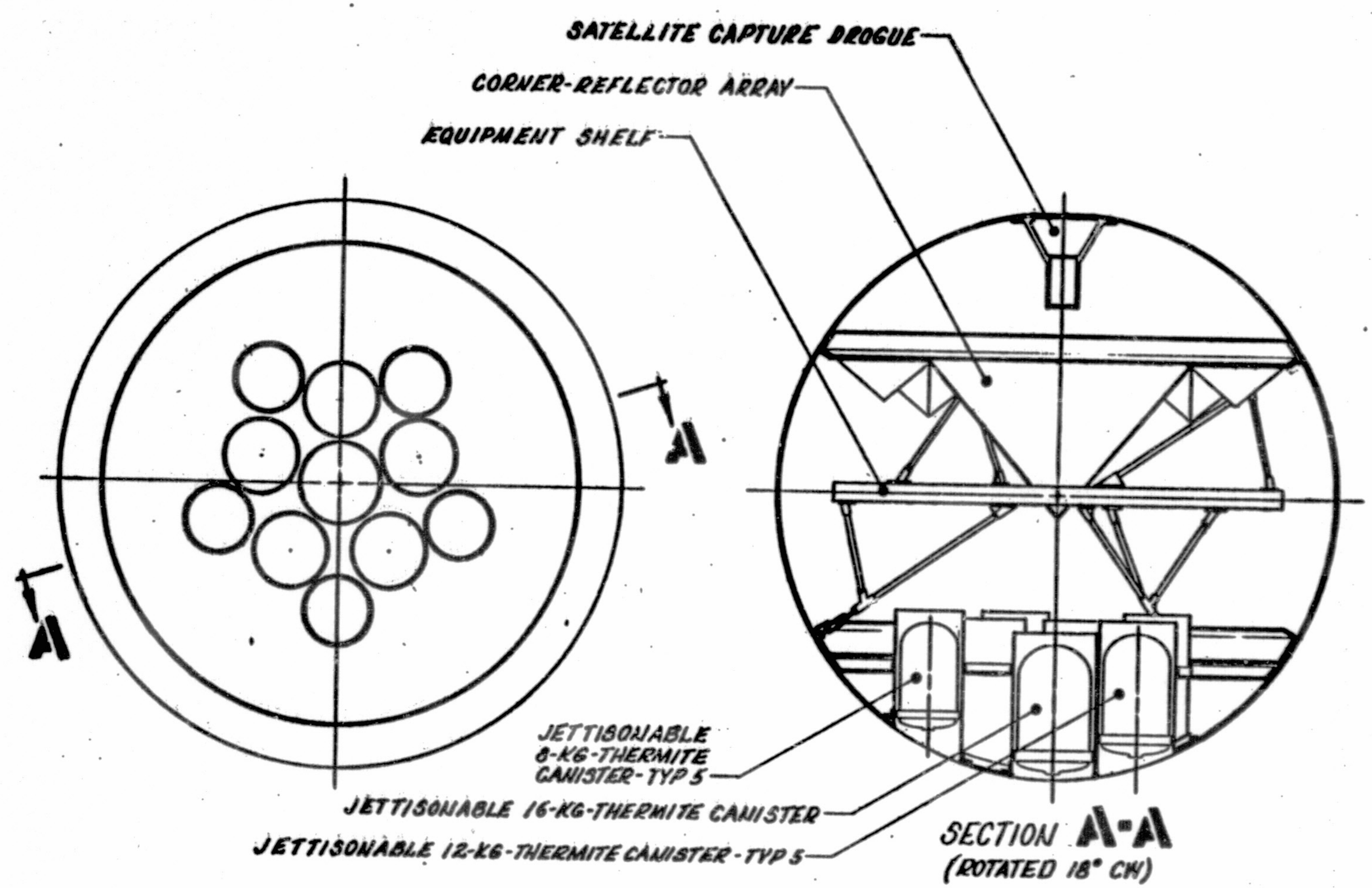
CHEMICAL RELEASE - MISSION REQUIREMENTS

ORBITAL INCLINATION	30°	OK FOR LIMITED EXPERIMENTS USING LOW LAT. OBS. SITES
	70°	REQUIRED FOR MEAS. OF GLOBAL WIND PATTERN OR PERTURBATION OF AURORAL CURRENT SYSTEM
ORBITAL ALTITUDE OF - RELEASE	120 TO 200 KM	
FLIGHT SCHEDULE	PROBABLE RESTRICTIONS ON TIME OF DAY, TIME OF YEAR, METEROLOGICAL CONDITIONS, AND PROXIMITY OF EARTH OBSERVATION SITES.	
CHEMICAL RELEASE - SEQUENCE	INDEPENDENT TRAILS - 10 EA. OF 1 MIN DURATION	
	TYPICAL MISSION DURATION 6 DAYS (144 HRS)	
	SINGLE BURST - GASEOUS RELEASE - AS MUCH MASS AS POSSIBLE - 400 KG DESIRED.	

CHEMICAL RELEASE - MISSION REQUIREMENTS

MISSION COMMUNICATIONS FROM POCC - DURING EXPERIMENT EXECUTION	- NEAR REAL TIME TO ORBITER, SATELLITE (VIA ORBITER), AND GROUND BASED OBSERVATION SITES.
PALLET/ORBITER-MOUNTED EQUIPMENT (EXPERIMENT PECULIAR)	- VERIFICATION FLIGHT "QUALITATIVE" OBSERVATION. - FOLLOW-ON MISSIONS = POSSIBLE USE OF OPTICAL SIGHTING EQUIPMENT, PHOTOMETER/CAMERA.
RELEASE (EXPULSION) LOCATION - POINT RELEASE MISSIONS	- LINE OF SIGHT FROM GROUND-BASED OBSERVATION LOCATIONS: ARECIBO, CHATENIKA, EISCAT FACILITY, ETC.
EXPULSION LOCATION PREDICTION ACCURACY (RE. EARTH COORDS)	- PLANAR - 5 KM - ALTITUDE - 3 KM

TETHERED SATELLITE - CHEMICAL RELEASE (THERMITE) CONFIGURATION



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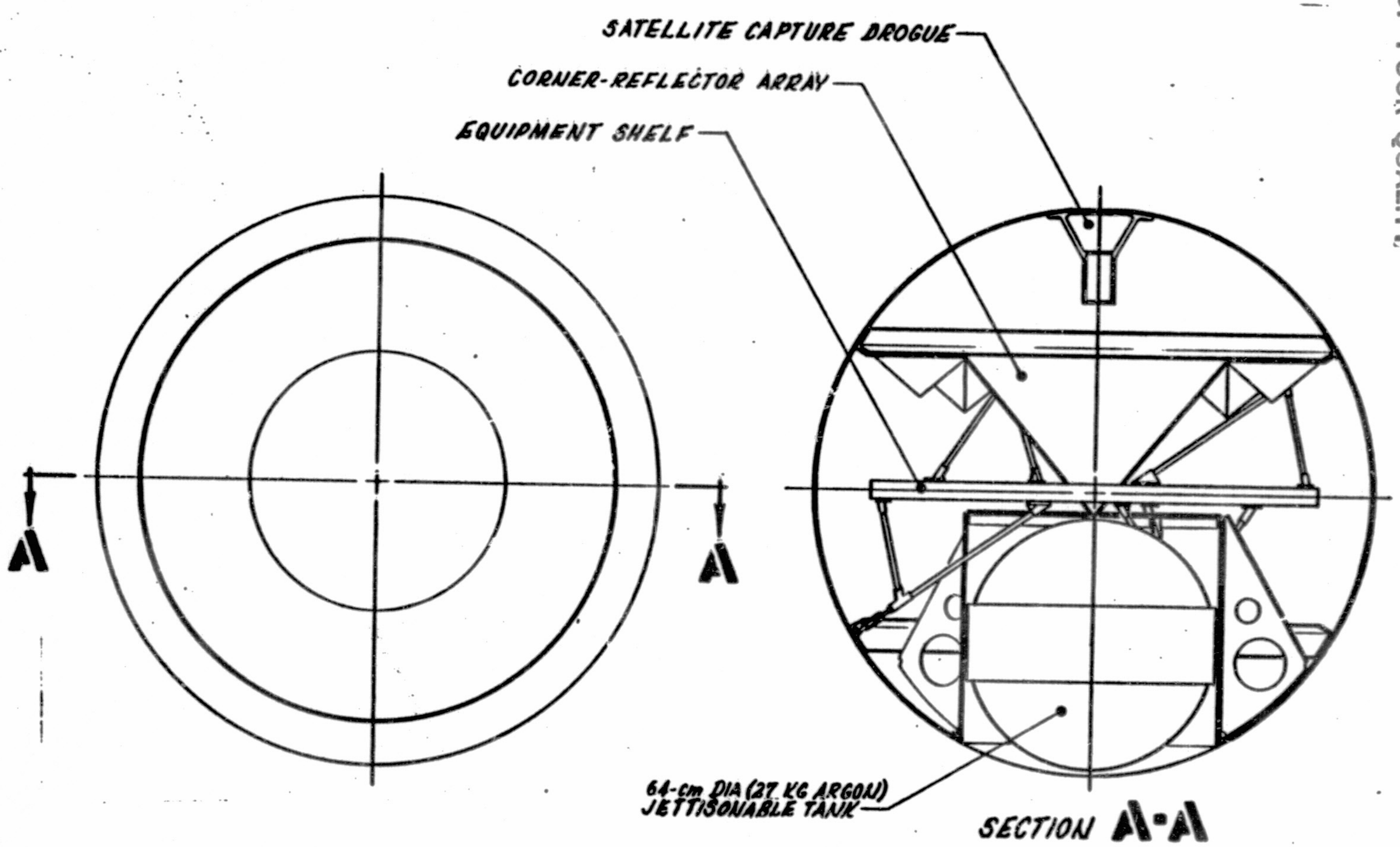
TETHERED SATELLITE - CHEMICAL-RELEASE (GAS) CONFIGURATION



CHEMICAL RELEASE CONFIGURATIONS - WEIGHT SUMMARIES

SUBSYSTEM	THERMITE CR WEIGHT (KG)	GAS CR WEIGHT (KG)
STRUCTURES (INCL. RADOME) & MECHS.	180.0	180.0
COMMAND & DATA HANDLING (INCL. CORN. REFL.)	34.0	34.0
ATTITUDE CONTROL & DETERMINATION	3.5	3.5
ELECTRICAL POWER	48.3	48.3
THERMAL CONTROL	37.8	37.8
PAYLOAD (SCIENCE)	242.0	138.0
TOTALS	545.6	441.6

NOTE: ALL WEIGHT ESTIMATES INCLUDE 15% CONTINGENCY

CHEMICAL RELEASE EXPERIMENT — STUDY RESULTS
"TRAIL" RELEASE

	EXPERIMENTERS GOAL	TSS CAPABILITY VERIFICATION MISSION	TSS CAPABILITY FOLLOW-ON MISSIONS
RELEASED MATERIAL	ALKALAI VAPOR (BA, LI, CS, ETC.)	BARIUM (TYPICAL 1-2 KG./RELEASE)	-
RELEASE (EXPULSION) METHOD	THERMITE OR ELECTRO VAPORIZATION	THERMITE REACTION	
NUMBER OF RELEASES (PER FLIGHT)	10	11+	10
MASS EXPENDED PER RELEASE (INCLUDING REACTION MATERIAL)	AS FEASIBLE	10-12 KG	10-18 KG*
DURATION OF RELEASE	1 MINUTE	50 SECONDS	
EXPULSION ALTITUDE	110 TO 160 KM	110 TO 160 KM	

* REQUIRES MODIFICATION OF BASIC SATELLITE EQUIPMENT SHELF

CHEMICAL RELEASE EXPERIMENT - STUDY RESULTS
GASEOUS, "POINT" RELEASE

	EXPERIMENTERS GOAL	VERIFICATION MISSION	FOLLOW-ON MISSIONS
RELEASED MATERIAL	GASES, CHEMI-LUMINSCENT MAT'LS. (TMA)	GASEOUS ARGON (TYPICAL)	-
EXPULSION METHOD		IGNITION OF SHAPED CHG. AFTER SEPARATION FROM SATELLITE)	LINEAR SHAPED CHG.
NUMBER OF RELEASES PER FLIGHT	-	1	1
MASS EXPENDED	400 KG.	27 KG. (ARGON)	40 KG.* 300-400 KG W/ "EXPENDABLE" SATELLITE
DURATION OF RELEASE	< 1 SEC	< 1 SEC	< 1 SEC
EXPULSION ALTITUDE	120-160 KM	110-125 KM	-

* USE OBLATE-SPHEROIDAL TANK

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ACCOMMODATION IMPACT - CHEMICAL RELEASE EXPERIMENT

- PROVIDE CANISTER MOUNTING AND RELEASE EXECUTION CIRCUITRY
- COORDINATE SAFETY AND OPERATIONAL PLANNING RELATED TO ACCOMMODATION OF CANISTERS

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F80-10

2300 – ATMOSPHERIC EXPERIMENT ACCOMMODATION

TSS SPACECRAFT CONCEPTUAL DESIGN ADAPTED FOR ATMOSPHERIC MISSION EXPERIMENT COMPLEMENT

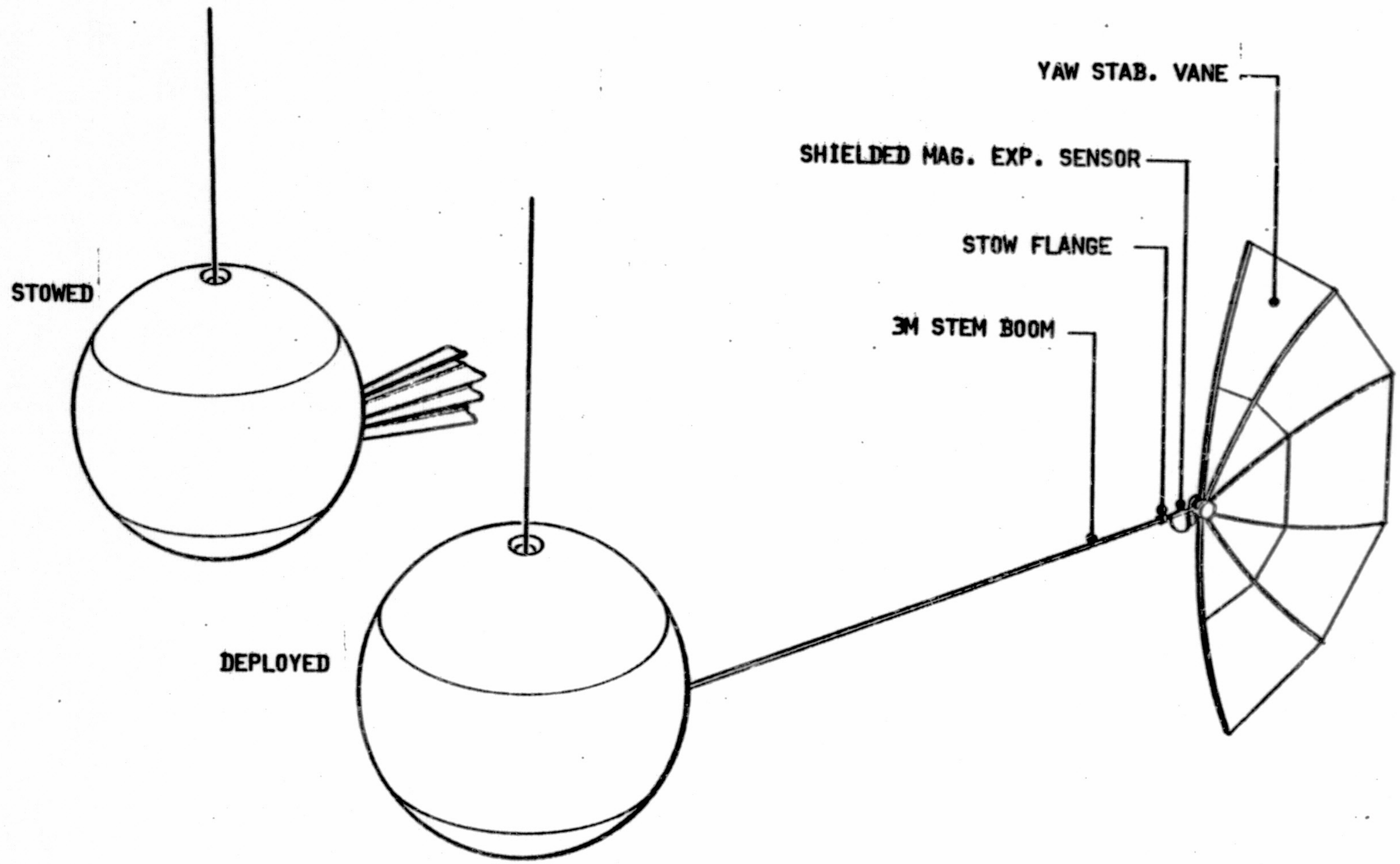

TABLE 1 ATMOSPHERIC SCIENCE TETHERED SATELLITE – MISSION REQUIREMENTS

ORBITAL ALTITUDES	125 - 150 KM.
ORBITAL INCLINATION	LOW INCLINATION OK - INITIAL MISSIONS HIGH INCLINATION DESIRED - LATER MISSIONS
DEPLOYMENT DIRECTION	DOWNWARD
DATA ACQUISITION SEQUENCE	FULL ORBITS OF DATA DESIRED SEVERAL DURING 7 DAY MISSION (INITIAL) 15 TO 30 DURING EXTENDED MISSIONS
FLIGHT SCHEDULE RESTRICTIONS	NONE
ORBITER BASED EXPERIMENT INSTRUMENTATION	NONE
REAL-TIME COMMUNICATION WITH ORBITER FROM POCC	HIGHLY DESIREABLE

TABLE 2. SATELLITE ATMOSPHERIC EXPERIMENT ACCOMMODATION REQUIREMENTS

- PHYSICAL PROPERTIES OF EXP.

	WEIGHT-KG(LBS)	VOLUME, $MTR^3(IN^3)$
TEMP. WIND, ATMOS., COMP. SENSOR (TWACS)	(20)	(600)
ION MASS SPECTROMETER (IMS)	(14)	(650)
RETARDING POTENTIAL ANALYZER (RPA)	(10)	(370)
ION DRIFT METER (IDM)	(9)	(320)
TOTALS	(53)	(1940)

• ELECTRICAL POWER - STANDBY	0.5 WATTS
ACTIVE	30 WATTS
• COMMANDS - DISCRETE	12
SERIAL - 32 BIT-MAX	4
• DATA RATE	8 KBPS
• ATTITUDE CONTROL ACCURACY - INST. AXIS RE VELOCITY VECTOR	2°
• ATTITUDE DETERMINATION ACCURACY RE VELOCITY VECTOR	± 0.1°
• EXTERNAL SATELLITE SURFACES	>15% OF AREA CONDUCTING

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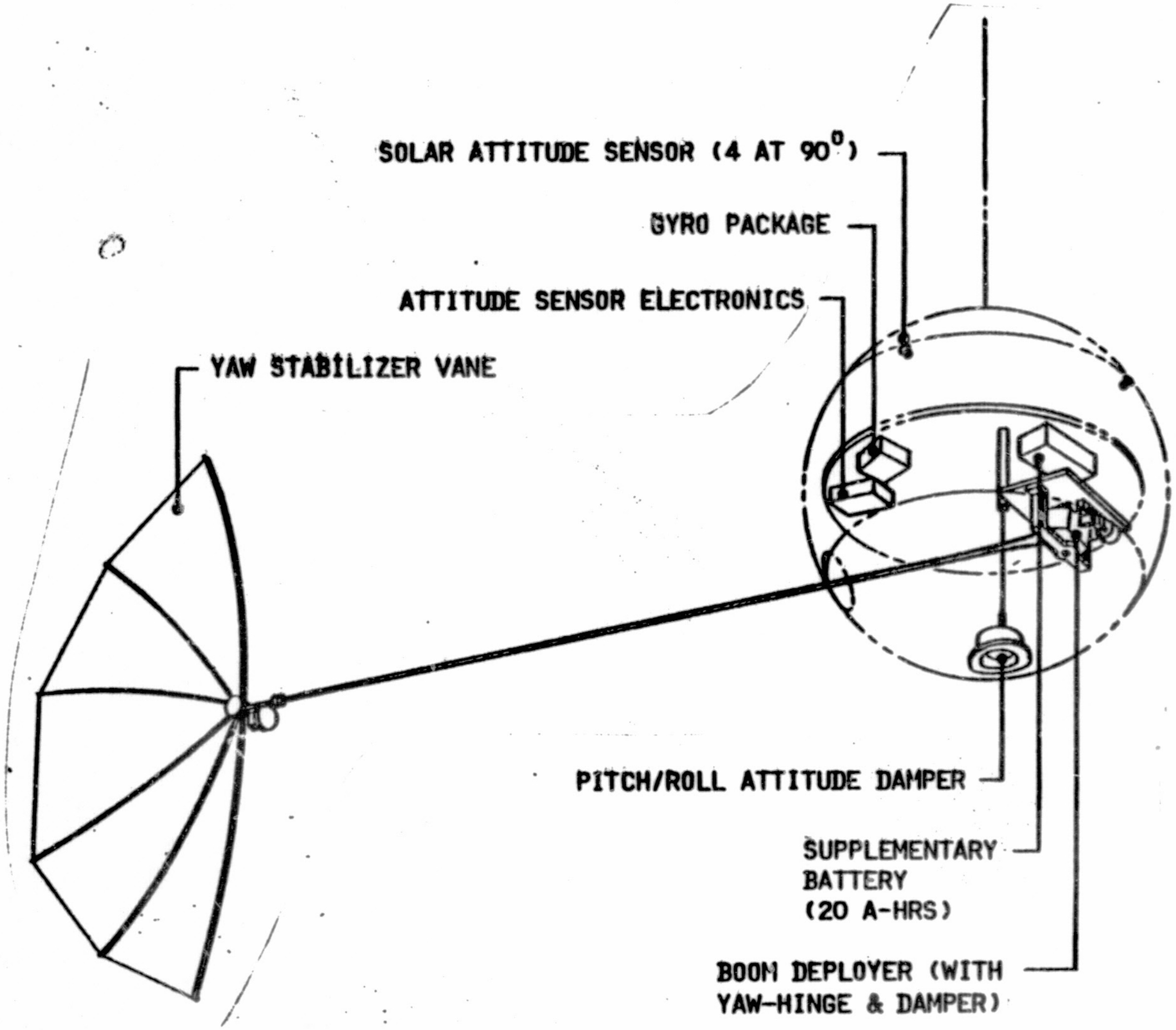
ATMOSPHERIC EXPERIMENT COMPLEMENT
PHYSICAL CHARACTERISTICS

COMPONENT		WT.KG.	SIZE-CM LXWXH*	LOCATION OF APERTURE (SIDE)
TWACS EXP.	- SENSOR	5.5	12x30x24	12x24
	ELECTRONICS	3.6	13x19x13	
IDM EXP.	- SENSOR	2.3	7x13x27	7x27
	- ELECTRONICS	1.8	14x18x11	
IMS EXPERIMENT		6.4	23x30x15	15x23
RPA EXP.	- SENSOR	2.7	7x14x28	7x28
	- ELECTRONICS	1.8	11x15x19	
		24.1 KG (53.1 LB)	.0333 MTR^3 (2032 IN^3)	

*LXW = MOUNTING SURFACE

ATTITUDE CONTROL & DETERMINATION SUBSYSTEM ELEMENTS ATMOSPHERIC MISSION EXPERIMENT COMPLEMENT



ACCOMMODATION IMPACT - ATMOSPHERIC EXPERIMENTS

- PROVIDE APERTURES ON FRONT SIDE OF SATELLITE FOR EQUIPMENT SENSORS
- INCREASE BATTERY COMPLIMENT TO FIVE PACKS (100 AMP-HOURS)
- PROVIDE YAW GYRO TO SENSE POSITION TO WITHIN 0.1°
- PROVIDE HEMISPHERICAL SOLAR SENSORS TO PROVIDE PERIODIC CALIBRATION OF YAW POSITION TO 0.1°
- PROVIDE INSTALLATION FOR LANGMIUR PROBE BOOM (SUPPLIED BY EXPERIMENTER)

ATMOSPHERIC EXPERIMENT ACCOMMODATION - STUDY RESULTS

- SET OF FOUR EXPERIMENTS (TEMPERATURE, WIND AND COMPOSITION SENSOR, ION DENSITY METER, ION MASS SPECTROMETER AND RETARDING POTENTIAL ANALYZER) CAN BE ACCOMMODATED BY MAKING MODIFICATIONS IN THE INTERNAL ARRANGEMENT TO ADD:
    - 3-AXIS GYRO PACKAGE AND SOLAR SENSORS TO PROVIDE $\pm 0.1^{\circ}$ ATTITUDE DETERMINATION
    - TWO ADDITIONAL BATTERY PACKS TO INCREASE STORED ENERGY CAPACITY TO 100 AMP. HRS.

- BASELINE DATA CAPACITY OF 8 KBPS MEETS EXPERIMENTERS REQUIREMENTS. DATA RATE COULD BE DOUBLED BY INCREASING TRANSMITTER POWER OR USE OF DIRECTIONAL ANTENNAS AS DESCRIBED IN COST OPTIMIZATION STUDIES.

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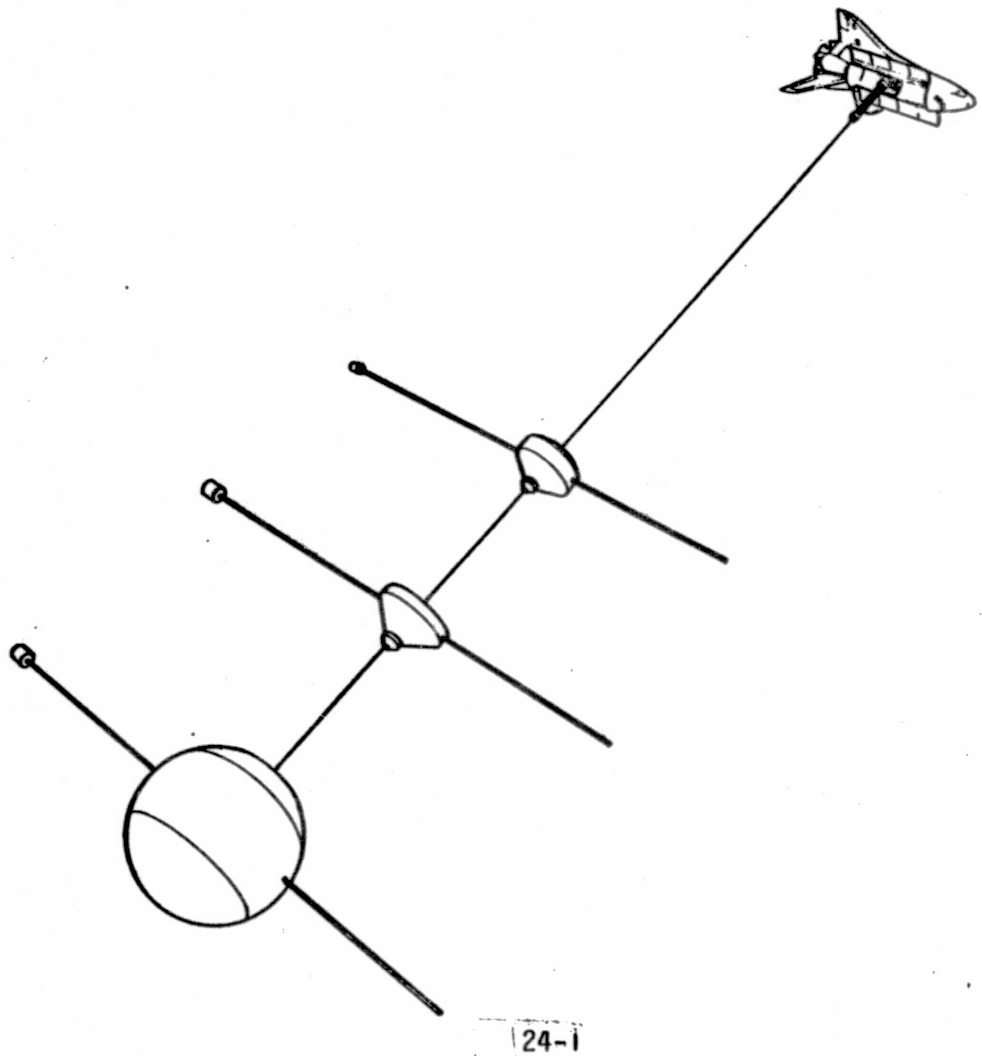
F80-10

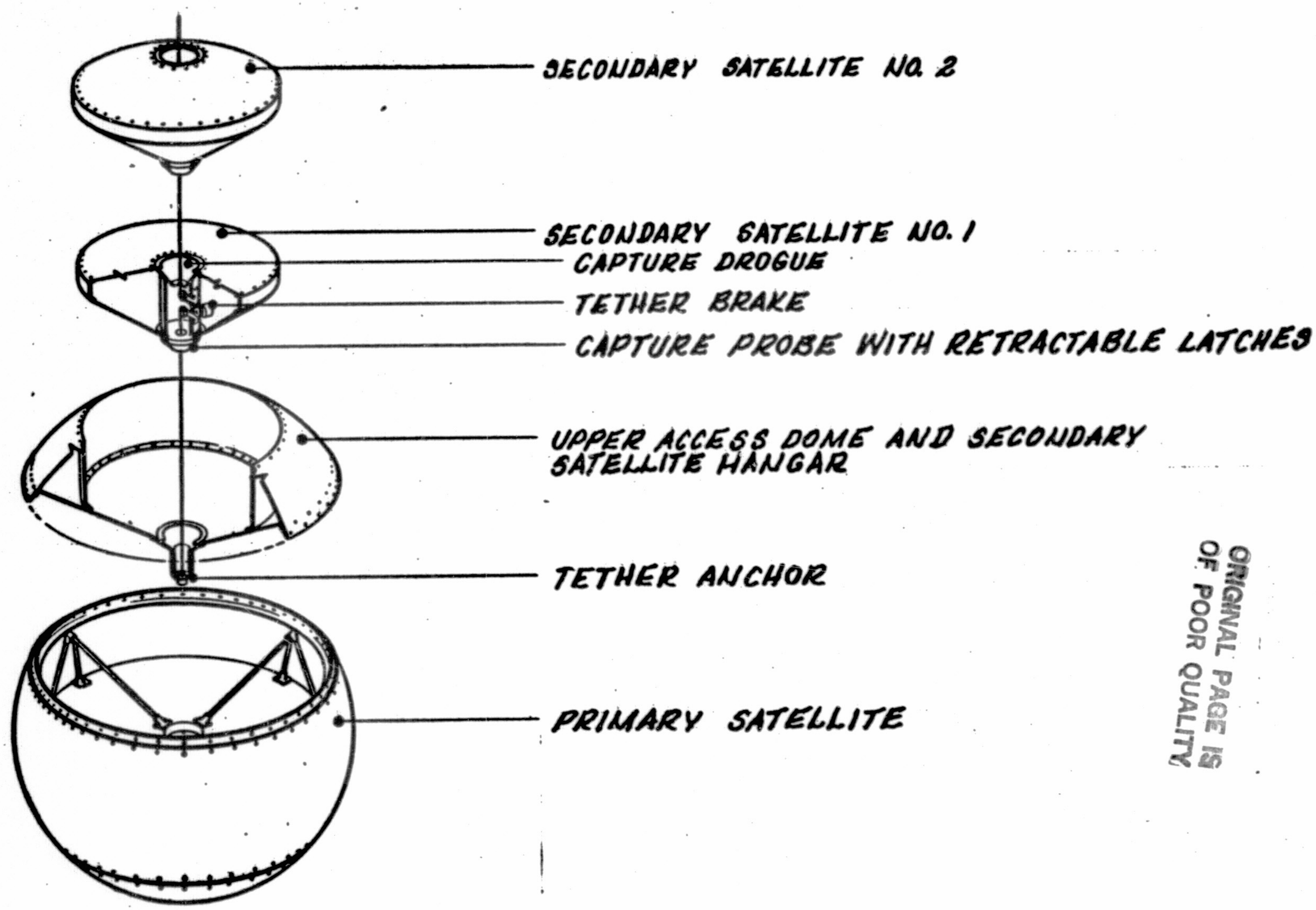
2400 – MULTIPLE SATELLITE EXPERIMENT ACCOMMODATION

F80-10

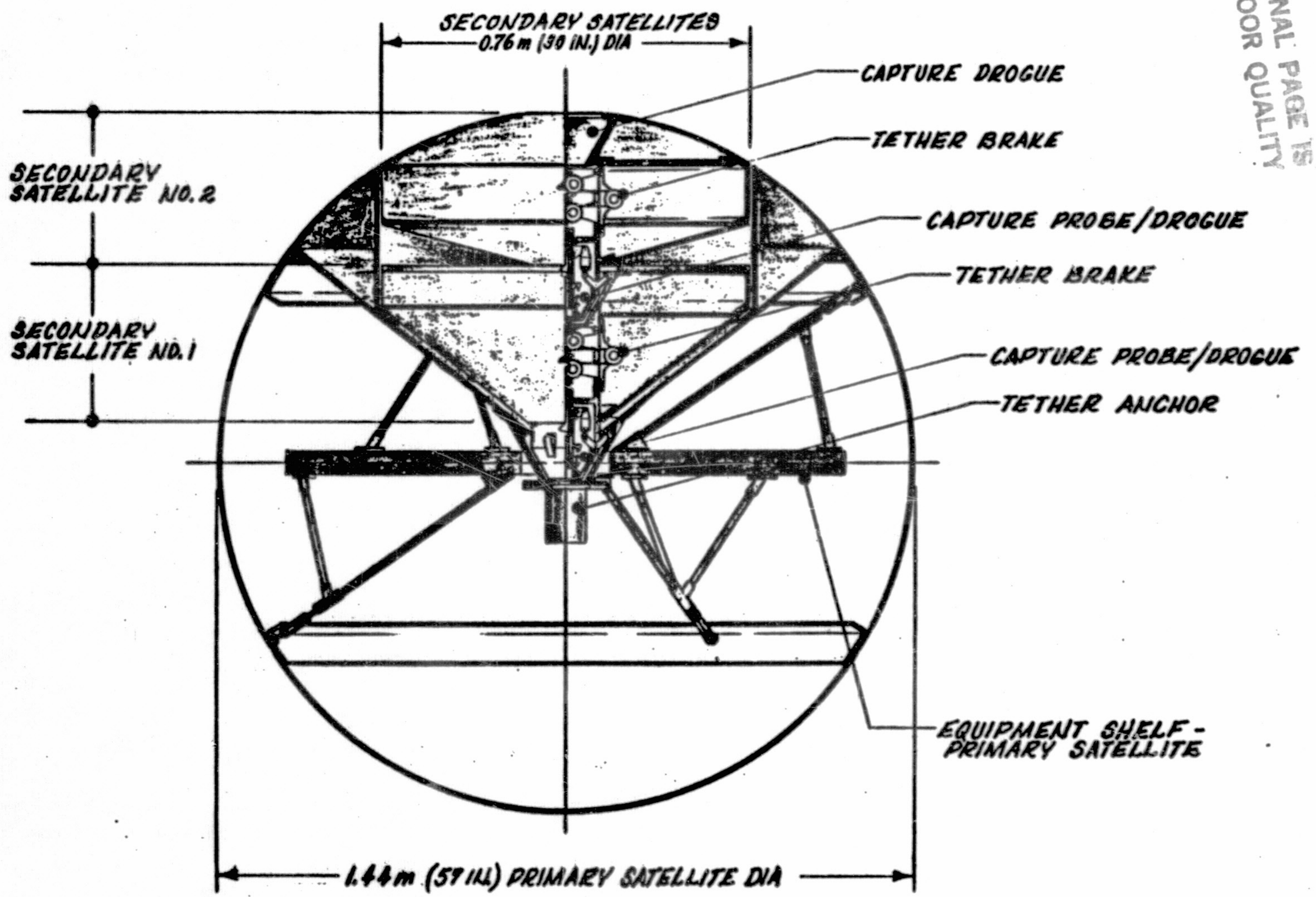
MULTIPLE SATELLITE CONCEPT



TETHERED SATELLITE ADAPTED TO ACCOMMODATE TWO SECONDARY SATELLITES



MULTIPLE-SATELLITE NESTED (PRE-DEPLOY) ARRANGEMENT



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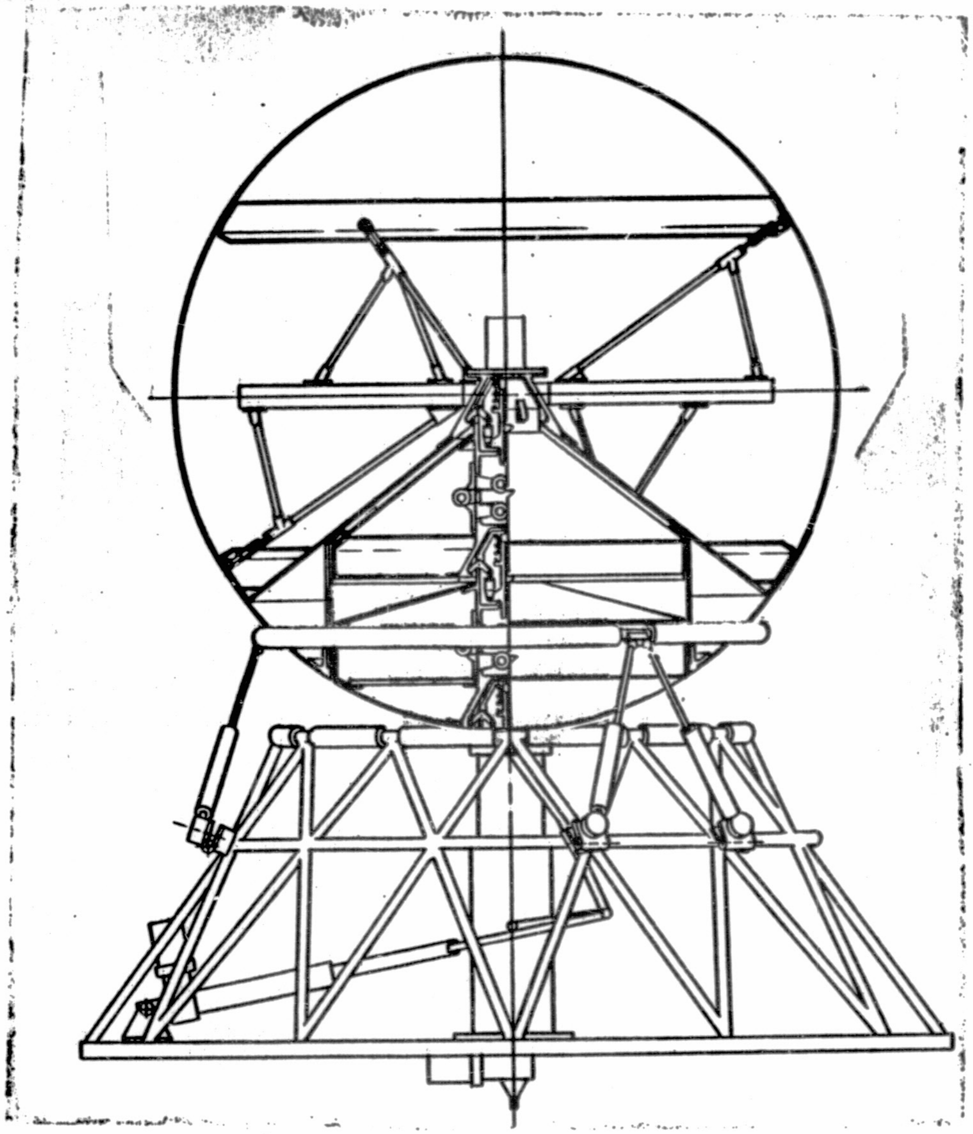
MULTIPLE SATELLITES - POSITIONED ON DEPLOYER



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MULTIPLE-SATELLITE WEIGHT SUMMARY

SUBSYSTEM	PRIMARY SAT WEIGHT (KG)	SECOND SAT #1 WEIGHT (KG)	SECOND SAT #2 WEIGHT (KG)
STRUCTURES AND MECHANISMS	215.5	20.0	20.0
COMMAND AND DATA HANDLING	23.0	5.0	5.0
ATTITUDE CONTROL AND DETERM.	3.5	0.0	0.0
ELECTRICAL POWER	48.3	10.0	10.0
THERMAL CONTROL	37.8	7.0	7.0
PAYLOADS (SCIENCE)	9.6	7.3	7.3
SUB TOTALS	337.7	49.3	49.3
TOTAL			387.0

NOTE: ALL WEIGHT ESTIMATES INCLUDE 15% CONTINGENCY

MULTIPLE SATELLITE STUDY CONCLUSIONS

- IN CONCEPT, DEPLOYMENT OF MULTIPLE SATELLITES SPACED ALONG TETHER APPEARS FEASIBLE
- ALTERNATE METHOD FOR DETERMINING SATELLITE POSITIONS WOULD BE REQUIRED SINCE BASELINE RETRODIRECTIVE RADAR REFLECTOR COULD NOT BE ACCOMMODATED
- QUANTITY OF DEPLOYMENT OPERATIONS IS SUBSTANTIALLY INCREASED OVER THAT OF THE BASELINE SYSTEM
- COST AND COMPLEXITY PROBABLY NOT COMPATIBLE WITH CONSTRAINTS AND PURPOSES OF VERIFICATION MISSION

F80-10

2500 – MAGNETOMETER EXPERIMENT ACCOMMODATION

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MAGNETOMETER EXPERIMENT ACCOMMODATION REQUIREMENTS

• DATA HANDLING	- SAMPLING INTERVAL--MIN	0.1 SEC
	- PRECISION (BITS)	8
	- DYNAMIC RANGE	2^{18} (262,000)
	- HOUSEKEEPING--ANALOG CH.	20
	--SAMPLING INTERVAL	15 SEC
	- BINARY STATUS INDICATORS	16
• COMMANDS	- DISCRETE	16
	- DIGITAL	4
	- STORED	--

MAGNETOMETER EXPERIMENT ACCOMMODATION REQUIREMENTS (cont'd)

• EXPERIMENT VOLUME--INTERNALLY-MOUNTED COMPONENTS	0.1 MTR^3
• WEIGHT, TOTAL--MAX.	15 KG
• POWER, AT 28V MAX.	15 WATTS
• ATTITUDE--REL. TO VEL. VECTOR	±20°
--CONTROL ACCURACY	NO REQUIREMENT
--READOUT ACCURACY	± 2°
--DRIFT (SLEW RATE) - YAW	1°/SEC
- PITCH & ROLL	10°/SEC
• SATELLITE POSITION DETERMINATION	
--EARTH COORDINATES	TBD

SATELLITE POSITION DETERMINATION
ACCURACY REQUIREMENTS

- TSS OPERATIONS - POSITION RELATIVE TO ORBITER

  RANGE - DERIVED APPROXIMATELY FROM TETHER LENGTH

  ACCURACY FOR R > 10 KM, SMALLER OF EITHER ± 1 KM OR 2%.
  FOR R < 1 KM - TBD

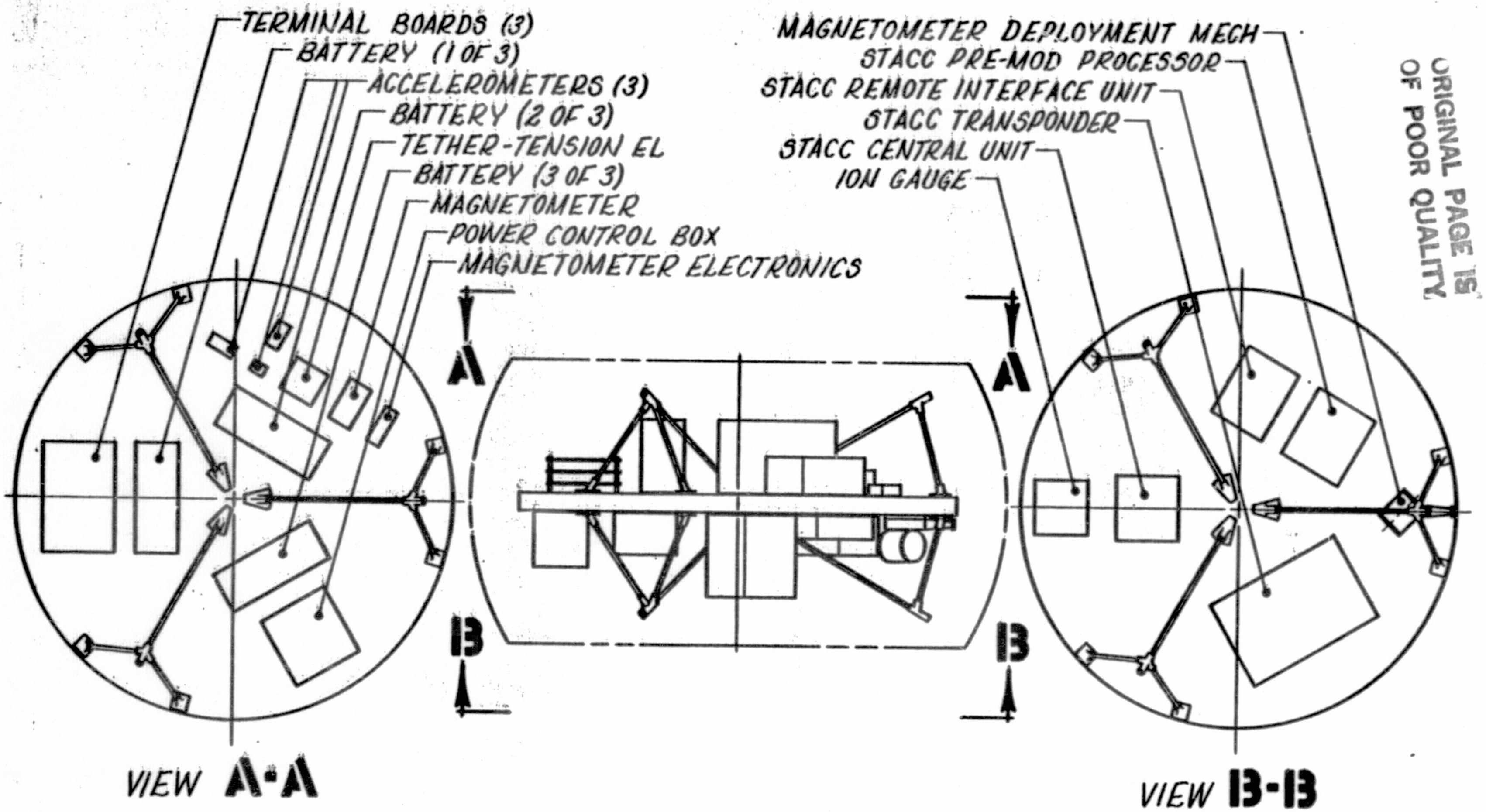
  ANGULAR POSITION RELATIVE TO NADIR - ± 2°

- MAGNETOMETER EXPERIMENT - ABSOLUTE ACCURACY RE EARTH COORDINATES - TBD

  - SPECTRAL DENSITY OF "SHORT TERM" <u>RELATIVE</u> POSITION MEASUREMENTS TO BE LESS THAN THAT OF MAGNETOMETER NOISE WITHIN BANDWIDTH OF DATA OF INTEREST (.003 TO 0.2 Hz)

- OTHER EXPERIMENTS - POSITION ACCURACY REQUIREMENTS TBD

MAGNETOMETER SATELLITE - INTERNAL ARRANGEMENT



Ball MAGNETOMETER SATELLITE - WEIGHT SUMMARY

SUBSYSTEM	WEIGHT (KG)
STRUCTURES AND MECHANISMS	185.5
COMMAND AND DATA HANDLING	23.0
ATTITUDE CONTROL AND DETERMINATION	3.5
ELECTRICAL POWER	48.3
ENGINEERING INSTRUMENT PACKAGE	9.6
THERMAL CONTROL	37.8
PAYLOAD EXPERIMENTS (SCIENCE)	1.2
TOTAL	308.9

NOTE: ALL WEIGHT ESTIMATES INCLUDE 15% CONTINGENCY

ACCOMMODATION IMPACT - MAGNETOMETER EXPERIMENT

- PROVIDE ADAPTOR FOR MOUNTING MAGNETOMETER SENSOR ON SATELLITE STABILIZATION BOOM
- ASSURE MAGNETIC CLEANLINESS OF SATELLITE IS SUFFICIENT FOR PROPER PERFORMANCE OF EXPERIMENT

MAGNETOMETER EXPERIMENT ACCOMMODATION – STUDY RESULTS

- THE ACCOMMODATION IMPACTS ON SATELLITE ARE RELATIVELY MINOR FOR OPERATION OF MAGNETOMETER IN "SCALER" MODE
    - LOW POWER CONSUMPTION
    - SENSOR MOUNTED ON EXISTING BOOM
    - SMALL PACKAGES
- SATELLITE ATTITUDE CAN BE DETERMINED TO WITHIN $\pm 0.1^{\circ}$ BY ADDITION OF 3-AXIS RATE INTEGRATING GYRO PACKAGE, AND SOLAR SENSORS
- EXPERIMENTER MUST PERFORM SUBSTANTIAL DATA REDUCTION TO CORRELATE RAW SATELLITE POSITION AND ATTITUDE DATA, AND REDUCE DATA FROM EXPERIMENT INSTRUMENT

F80-10

2600 – "COMBINATION" MISSION – EXPERIMENT ACCOMMODATION

IMPACT ON BASELINE CONFIGURATION PECULIAR TO "COMBINATION" MISSION EXPERIMENT COMPLEMENT

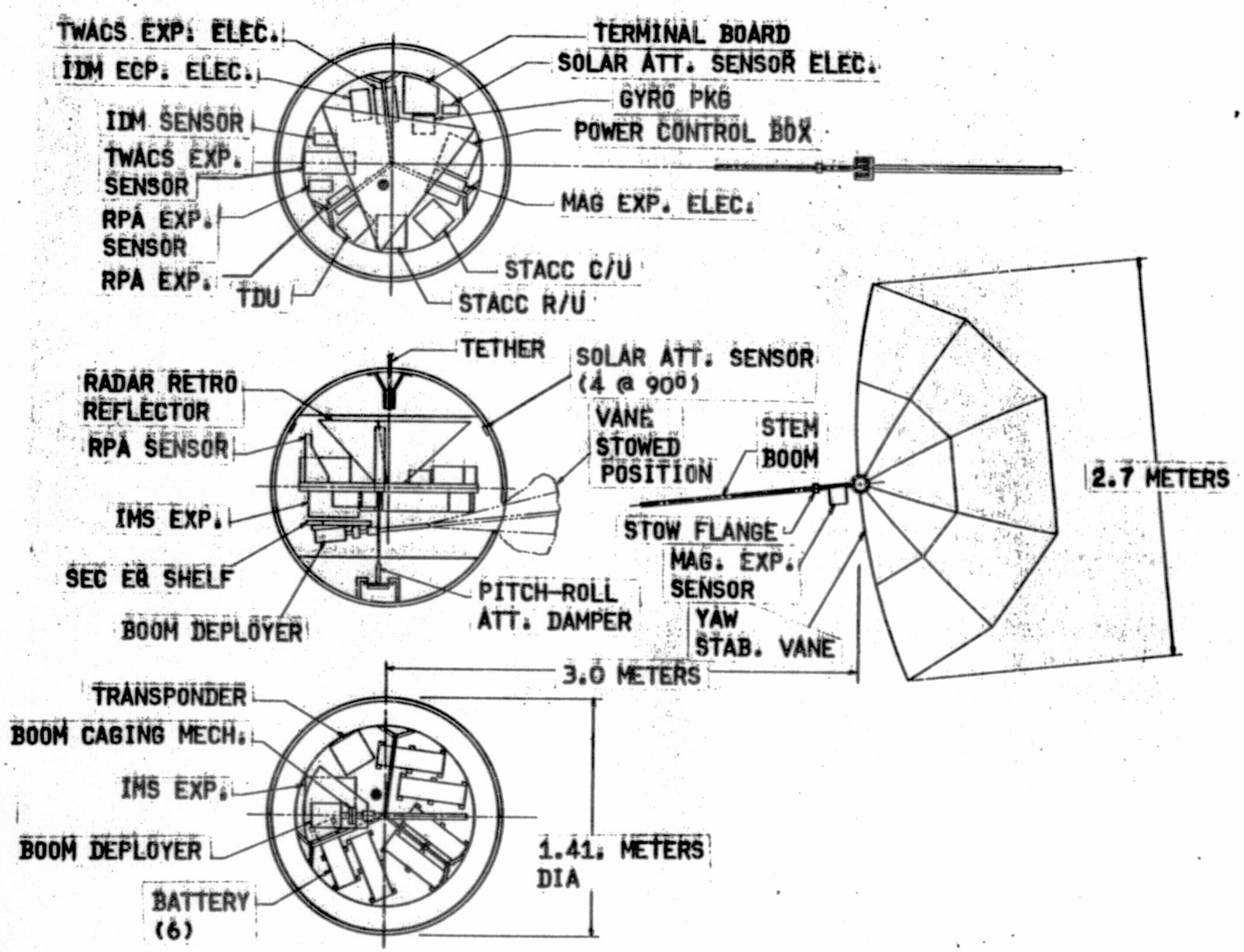
EXPERIMENT COMPLEMENT CONSISTS OF:

- MAGNETOMETER (MAG)
- TEMPERATURE, WIND, AND COMPOSITION SENSOR (TWACS)
- ION MASS SPECTROMETER (IMS)
- RETARDING POTENTIAL ANALYZER (RPA)
- ION DRIFT METER (IDM)

IMPACTS:

- PROVIDE ALL FEATURES ENUMERATED AS PECULIAR TO ACCOMMODATION OF "MAGNETOMETER" AND "ATMOSPHERIC" EXPERIMENT COMPLEMENTS
- INCREASE BATTERY COMPLEMENT TO FIVE, 20 AMP-HOUR PACKS (100 AMP-HOUR TOTAL AT 28V)

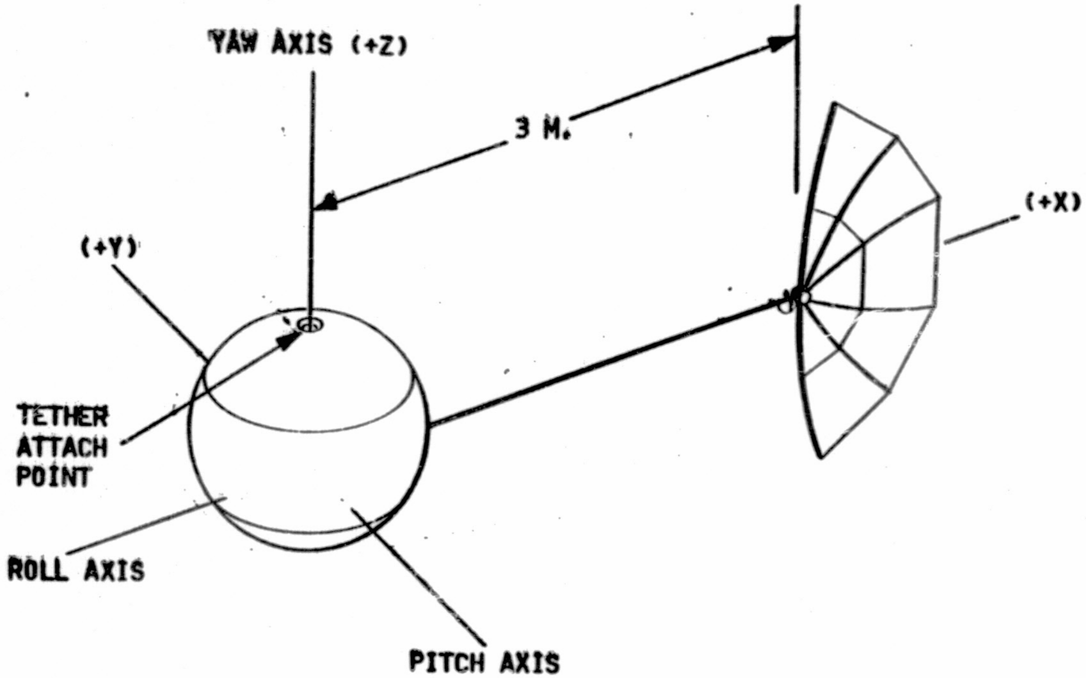
GENERAL ARRANGEMENT - ADAPTED FOR "COMBINATION" EXPERIMENT COMPLEMENT



T-SAT - WEIGHTS SUMMARY "COMBINATION" MISSION

		WEIGHT LBS	KG
STRUCTURE AND MECHANISMS (INCLUDING RADOME)		276	125
ELECTRICAL POWER AND DISTRIBUTION (INCLUDING 120 A-HR BATTERY)		174	79
THERMAL CONTROL		51	23
ATTITUDE CONTRL AND STABILIZATION		13	6
COMMAND AND DATA HANDLING AND POSITION DETERMINATION (INCL. RETRO REFLECTOR)		64	29
ENGINEERING INSTRUMENTATION		24	11
EXPERIMENT PAYLOAD		56	26
MAGNETOMETER	3		
TEMPERATURE, WIND AND COMPOSITION SENSORS	20		
ION DENSITY METER	9		
ION MASS SPECTROMETER	14		
RETARDING POTENTIAL ANALYZER	10		
		659	299
15% CONTINGENCY			45
TOTAL			344

SATELLITE MOMENTS OF INERTIA "COMBINATION" (VERIFICATION) MISSION



	MOMENTS OF INERTIA ($Kg\text{-}MTR^2$)		
	PITCH	ROLL	YAW
• ABOUT BODY PRINCIPAL AXES			
MAIN BODY	42	42	53
BOOM & VANE	27	.5	27
• ABOUT TETHER ATTACH POINT			
MAIN BODY	125	125	53
BOOM & VANE	30	6	27
TOTAL SATELLITE	155	131	80

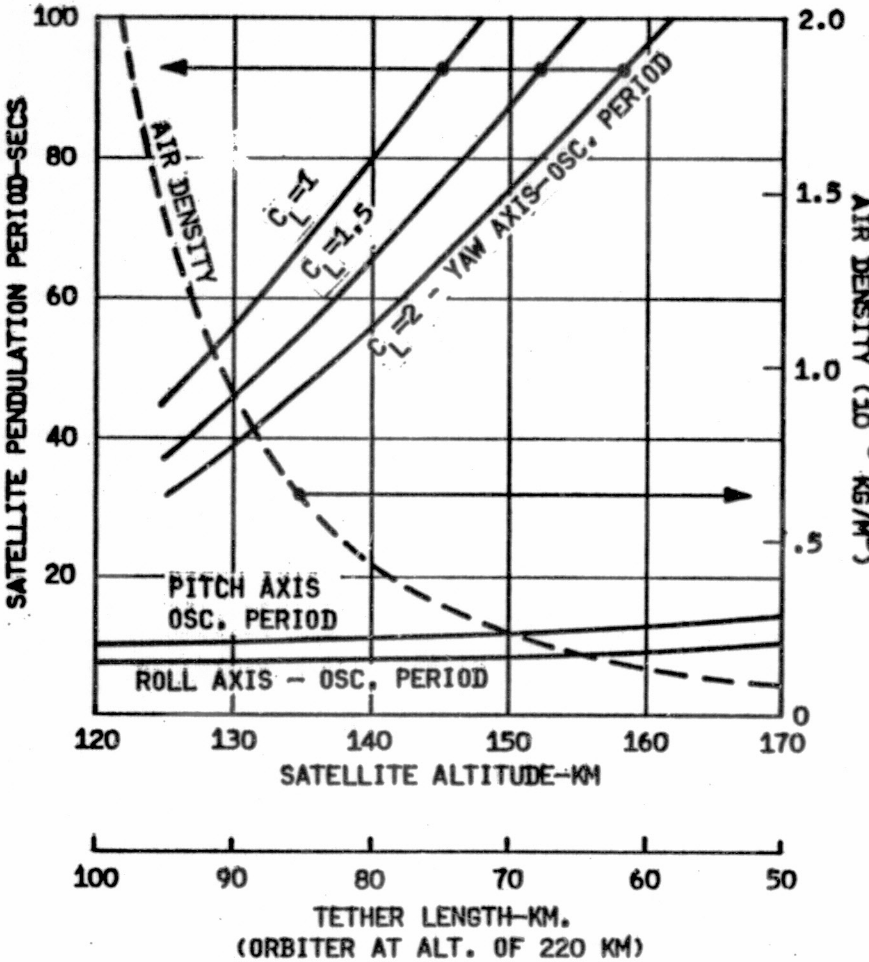
ELECTRICAL POWER BUDGET – "COMBINATION" EXP. PAYLOAD (VERIFICATION FLIGHT)

	STAND-BY PWR-WTS	OP.PWR WATTS	12 HR.PERIOD DEPLOYMENT ENERGY-W-HRS. 80% STBY	12 HR.PERIOD RETRIEVAL ENERGY-W-HRS. 20% OP.	23 HR. ON STATION OPERATION 100 % DUTY CYCLE
X-PONDER-(2.5W.R.F.)	2	24	19.2	57.6	552
STACC R/U	1.1	1.1	10.6	2.6	25.3
STACC C/U	0.9	10.9	8.6	26.2	250.7
TM DIST. UNIT		1		2.4	23
ACCELLEROMETERS	-	1		2.4	23
PWR.DIST.&CONTL.	1	1	9.6	2.4	23
GYRO PACKAGE	-	20			460
SOLAR SENSORS	-	1		2.4	23
TEMP INSTRMT'TION	-	2		4.8	46
EXPERIMENT PAYLOAD	.5	35	4.8	1.2	805
			38	100.8	2185

TOTAL ENERGY REQ'D: WATT-HRS	2324
AMP-HRS AT 28V	83
AVAILABLE FROM 100 A-HR BATTERY (5 20A-HR STRINGS) 90% DOD	90
ENERGY MARGIN	+ 7 AMP-HRS.

SMALL ANGLE SATELLITE PENDULATION & OSCILLATION-PERIODS. YAW FREQ. BASED ON 1 MTR VANE EXPOSURE (AIR DENSITY JACCHIA 71 MODEL 80-81 SOLAR MAX)

C-4



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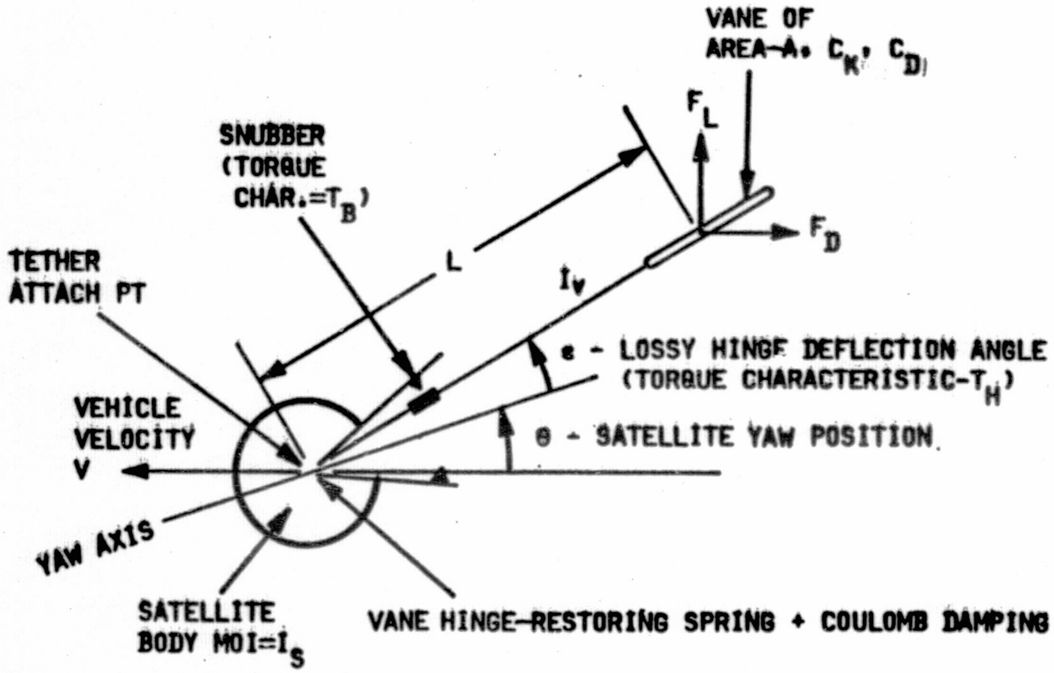
YAW STABILIZATION-SIMULATION GEOMETRY



EQUATIONS OF MOTION:

<u>VANE</u> $\frac{\rho V^2 LA}{2}\,\mathrm{SIN}(\theta+\varepsilon)\left[C_D|\mathrm{SIN}\phi|+C_L|\mathrm{COS}\phi|\right] + T_B + T_H = -I_V(\ddot{\theta}+\ddot{\varepsilon})$

<u>MAIN BODY</u>: $T_B+T_H = I_S\ddot{\theta}$; $\phi = \theta+\varepsilon$

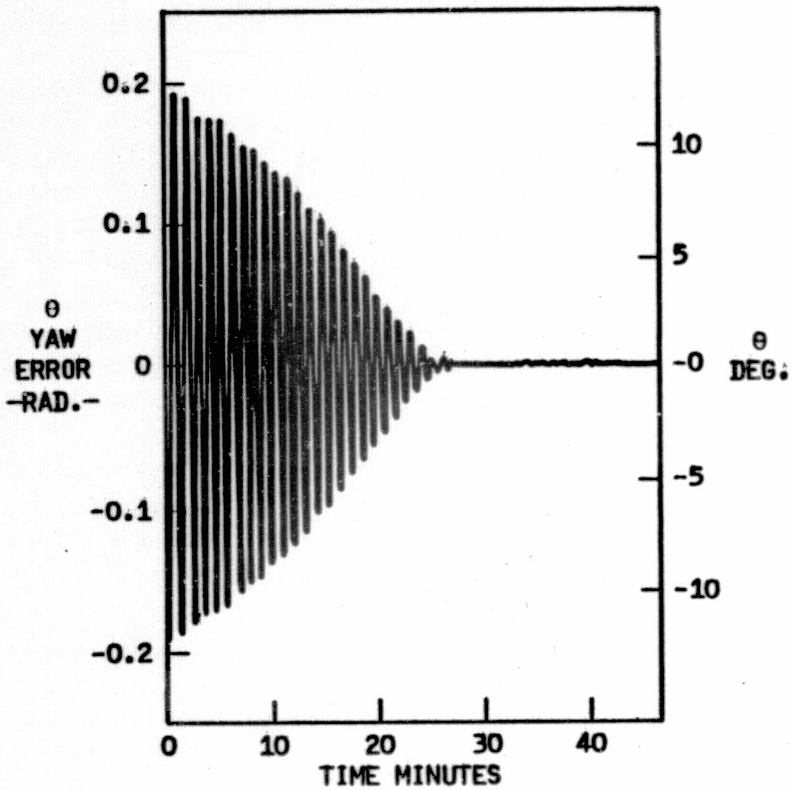
HINGE & SNUBBER CHARACTERISTICS:

$T_B = k_B\varepsilon^3$; $T_H = k_R\varepsilon + k_D\left|\frac{\dot{\varepsilon}}{\dot{\varepsilon}}\right|$

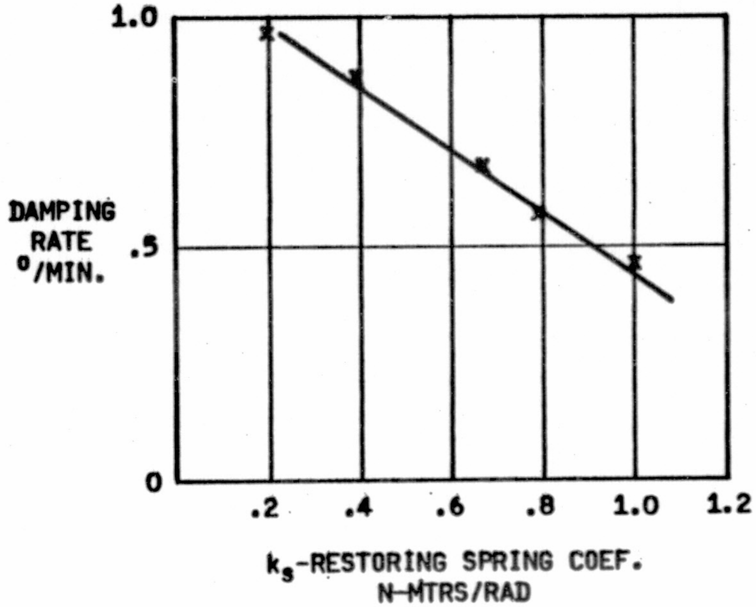
YAW STABILIZER SIMULATION VARIABLES AND COEFFICIENTS

A	- VANE AREA	1 MTR^2
ℓ	- BOOM LENGTH	3.5 MTRS
I_V	- BOOM & VANE MOI (ABOUT TETHER ATTACH POINT)	27 $KG\text{-}MTR^2$
I_S	- MAIN SATELLITE BODY MOI (ABOUT TETHER ATTACH POINT)	53 $KG\text{-}MTR^2$
θ	= SATELLITE YAW POSITION	RADIANS
ε	= BOOM HINGE DEFLECTION	RADIANS
ρ	= ATMOSPHERIC DENSITY	.15 TO 1.5×10^{-8} KG/MTR^3
C_L, C_D	= VANE COEF. OF LIFT & DRAG	1-2
k_B	= SNUBBER COEFFICIENT	7 $N\text{-}MTRS/RAD^3$
k_H	= RESTORING SPRING CONSTANT	.2 - 1.5 N-MTRS/RAD
k_D	= COULOMB FRICTION COEF.	.002 - .02 N-MTRS
V	= ORBITAL VELOCITY	8,000 MTRS/SEC

SMALL ANGLE YAW ACQUISITION SENSITIVITY TO VALUE OF BOOM HINGE SPRING CONSTANT–WITHOUT SNUBBERS



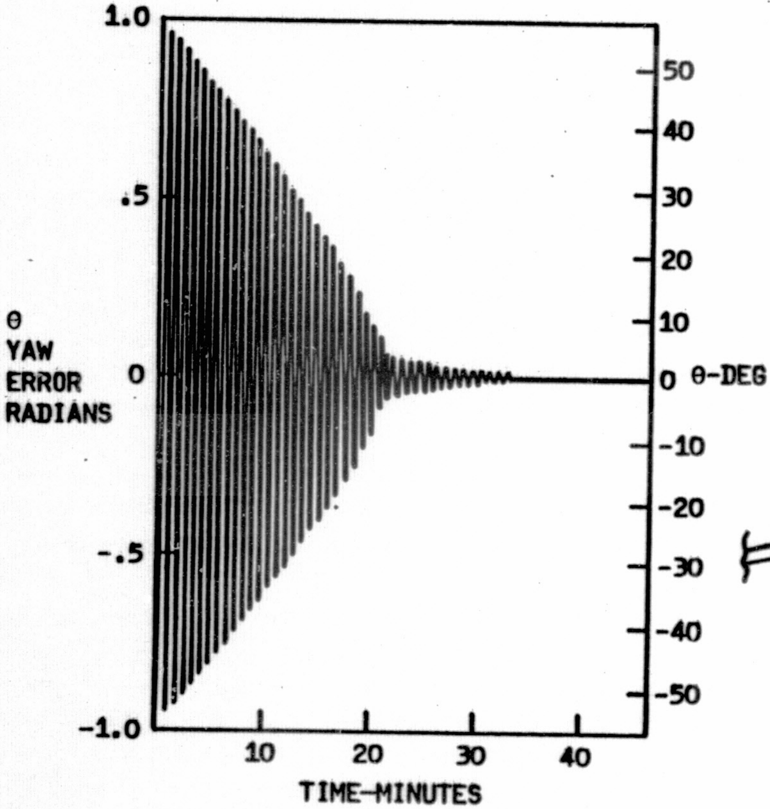
TYPICAL SMALL ANGLE ACQUISITION
k_s=1.0, k_d=0.0033



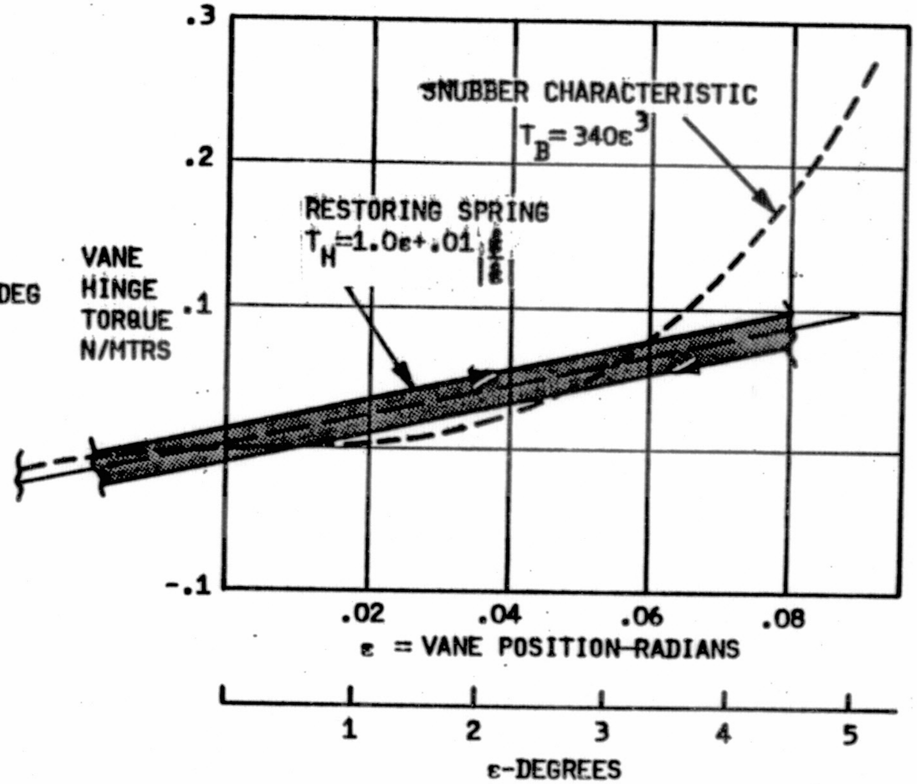
SENSITIVITY OF ACQUISITION RATE TO RESTORING SPRING COEFFICIENT – k_s

k_d=.0033, $\rho=1.1\times10^{-8}$ KG/MTR^3

TYPICAL LARGE-ANGLE YAW ACQUISITIONS WITH SNUBBER SIMULATED



TYPICAL LARGE-ANGLE ACQUISITION
$K_R = 1.0$, $K_D = 0.066$



RESTORING SPRING & SNUBBER CHARACTERISTICS